Vision for grid and legal developments for a RES-dominant power system in Saudi Arabia

F. Georges, *EGI, Belgium,* A. Chaouachi, *EGI, Belgium,* G. Papaefthymiou, *EGI,* I. Gerkens, *EGI, Belgium, Germany,* R. Allan, *Pinsent Masons LLP, UAE,* I. Alajaji, *Al Sabhan & Al Alajaji Law Firm, Saudi Arabia*

***Abstract* - The Kingdom of Saudi Arabia (KSA) moves towards integrating more Renewable Energy Sources (RES) in the power system. This paper outlines a comprehensive grid planning process for a cost-efficient and reliable integration of RES. The process is composed of six fields of practices:**

(i) scenario building to frame the uncertainties around the electricity sector,

(ii) enhanced market modelling to identify future generation dispatches with a higher RES penetration

(iii) year-round probabilistic grid modelling considering the volatility of RES generation,

(iv)cost and benefit analysis to select the best investments,

(v)techno-economic assessment of the generation fleet and design of new cross-border interconnections

(vi)dynamic portfolio management to steer investment projects in a changing environment. The paper outlines how such an approach could be applied to the case of KSA, towards the creation of a hub connecting three continents.

This paper ends with highlights of the legal and regulatory Saudi aspects related to RES integration.

***Index Terms*— Cost-benefits analysis, grid planning, legal, portfolio management, power system, regulatory aspects, RES integration, scenarios**

I. Introduction

Grid planning is to be considered today under a changing and highly uncertain environment in the energy sector. In the past, connecting new power plants and steadily growing demand were the main investment drivers, both relatively forecastable, in intensity and location, within the vertically integrated companies.

In the Kingdom of Saudi Arabia (KSA), the rollout of the Vision 2030 [1] sets ambitious plans for diversifying the economy. This plan poses key challenges for the power sector in the coming years, in the form of a combination of high load growth with a radical transformation of the generation mix from oil and gas to variable renewable energy sources (such as solar and wind) [2] and nuclear energy [3]. In this context, National Grid SA faces significant uncertainties regarding the possible development paths of the electricity system.

Today, the market expansion to include independent power producers (IPPs), RES integration, electrification of transport, heating/cooling sectors and energy efficiency measures result in higher complexity of planning and development provisions [3]. On the one side, integration and location of IPPs as well as new renewable generation cannot always be indicated clearly. On the other side, the combined effect of a more electricity dependent society, and local distributed generation and efficiency measures increases
the complexity regarding demand prediction in the future, which could lead to negative demand forecasting in some instances [4],[5].

Within this context, the development of the future grid should be compatible with increased uncertainty [6]. Decisions taken today should ensure that the grid architecture of tomorrow can fulfill the requirements of the grid users in a cost-effective fashion.

However, the grid cannot be designed to cover all possible scenarios. This approach would be very expensive as there are many possibilities to cover, and would lead to stranded asset investments; i.e. projects which are useless. This paper proposes an approach for designing a robust investment portfolio meeting all reasonable future requirements of grid users (i.e. scenario-based grid planning), and suggests to steer the portfolio periodically by adopting and optimizing the investment projects selection. This paper ends with highlights of the legal and regulatory Saudi aspects related to RES integration.

Whereas in the past, the operation of a power system was focused on aligning power plants to cover a relatively predictable demand pattern, RES generation is weather-dependent and volatile by nature. This means that power systems are subject to a broad range of fast changing conditions. Against this background, we propose the implementation of year-round (probabilistic) grid modelling, in order to get a robust evaluation of the power system, covering a wide range of operational states, compared to conventional peak-hour assessment (relevant for demand-driven power systems).

F. Georges is head of grid planning, market and operations at Elia Grid International, Belgium (e-mail: fabian.georges@eliagrid-int.com).

A. Chayouchi is senior power system expert at Elia Grid International, Belgium (e-mail: aymen.chaouachi@eliagrid-int.com).

G. Papaefthimiou is senior power system expert at Elia Grid International, Germany (e-mail: georgios.papaefthimiou@eliagrid-int.com).

I. Gerkens is senior market & regulatory experts at Elia Grid International, Belgium, (e-mail: isabelle.gerkens@eliagrid-int.com).

R. Allan is a senior associate at Pinsent Masons LLP, an international law firm, and is based in Dubai, UAE (e-mail: rita.allan@pinsentmasons.com).

I. Alajaji is a partner at at Al Sabhan & Al Ajaji Law Firm in Riyadh, Saudi Arabia (e-mail: mailto:ibrahim@saajlaw.com).

The increasing need for new grid infrastructure in a regulated environment requires qualitative and quantitative justification to internal and external stakeholders, who will question and challenge a large grid investment program, given the required capital expenditure. The regulator will have questions too since these expenditures will be covered by tariffs. When public granting and the associated public consultation takes place, authorities, public institutions and public society will question the infrastructure development and its associated environmental and social impacts. Focus on public acceptance and stakeholders engagement, both internally and externally, is therefore key to the creation of a shared understanding to achieve a broad buy-in on the necessary investment.

For this purpose, the proposed methodology includes early engagement, taking into account information exchanges and harmonized assessment of the cost and benefits of the new infrastructure (i.e. cost-benefits analysis). As a result, negotiation and identification of the possible mitigation measures to limit the environmental impacts will leverage acceptance on the new grid projects.

II. Proposed Grid Design methodology

The proposed holistic approach to design a future-proof grid architecture can be visualized as a process consisting of several steps (see Fig. 1). During that process, constant attention is given to public acceptance and stakeholder engagement in a pathway to build a common agreement on the investment policy.

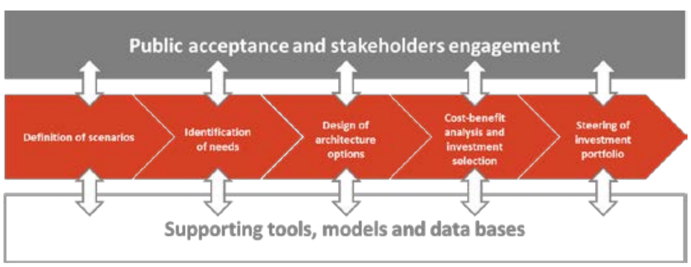

Fig. 1. Methodological breakdown.

A. Scenario building

First of all, different scenarios for possible evolutions of the energy sector and energy mix have to be defined. These can include conservative and disruptive evolutions. Stakeholder engagement is crucial already at this stage to ensure early consensus on the outcome of the process. The data collection to define scenarios, as referred in [7], can be summarized as following:

- Defining the time horizon(s) to be considered in the grid planning study (typically from 5 to 20 years);
- Exhaustive listing of all the uncertainties around the evolution of the energy mix;
- Sorting uncertainties relative to their impact on the power sector;
- Preparing a qualitative definition of scenarios, framing and structuring the possible evolutions of the energy mix, based on the major uncertainties. The scenarios are articulated around the most influencing uncertainties, e.g. nuclear, RES, market integration, fossil with carbon capture storage or demand in the case of e-highway 2050 [8];
- Quantifying the scenarios taking into account studies, policies papers, governmental sources, manufacturers technical specifications etc.;
- Performing specific modeling to identify explicit parameters, e.g. level of security of supply, number and sizing of controllable or flexible generation etc.;
- Discussion with stakeholders and fine-tuning of scenarios to include their feedback.

The resulting identified scenarios can be mapped according to their main features, as depicted in Fig. 2. For each of the identified scenarios, the associated investment needs must also be estimated according to complementary models.

Fig. 2. Example of scenarios and their articulation around the key structuring parameters [8].

B. Market modelling

In a given scenario, a market study assesses the required production to meet the expected demand. The electricity generation dispatch (Fig. 3) is modeled by minimizing the generation costs, taking into account its cost function, availability and constraints. These characteristics of production depend on several parameters such as the price of fuel, weather conditions, demand and so on.

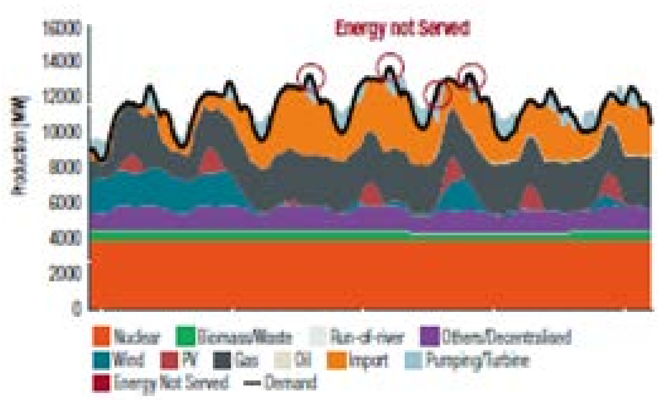

Fig. 3. Example of weekly power dispatch, by production type.

The random nature of the weather conditions needs to be covered by suitable probabilistic modeling. The demand for electricity and its variability throughout the year must also be integrated in the model. The presence of production at the voltage levels of the distribution networks may require a good modeling compromise between the desired complexity and accuracy.

In addition, energy exchanges between countries have an important role in social welfare maximization. A wide perimeter of countries is thus simulated in order to visualize possible scenarios of cross-border power flows. In this context, the supply and demand assumptions in neighboring countries, considering assumptions of capacities available for trade between countries are modeled as “Net Transfer Capacity”. (In reality, KSA's ability to export or import electricity is in fact limited because of its unique 60 Hz grid frequency, which limits the options for cross border grid interconnections.)

Once these elements are established, the modelling results in an estimate of the power dispatches of the units planned in each country, at each hour of the year of the scenario studied. With the growing integration of renewables in the system, conventional units dispatches will be highly variable, leading to changing operating conditions on the network as well.

C. Advanced power system modelling

RES-dominated power systems are challenged by changing operating conditions. The traditional peak and off-peak methodology fits a demand-driven grid planning whereas a RES volatile market requires an extended grid assessment using year-round (probabilistic) approaches.

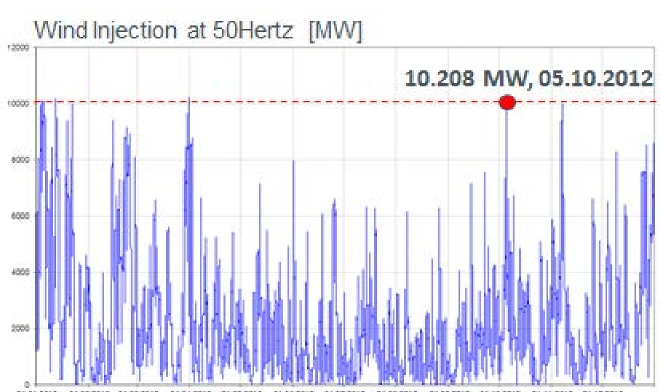

Fig. 4. Illustration of a volatile RES system (i.e. wind)

In year-round system modelling, the studied points in time (i.e.. an hour) are chosen to map all possible situations identified through market simulations. These cases explore a great variety of situations: frequent cases or rare cases but resulting in particularly stressed system conditions.

Market simulations result in 8760 hourly power dispatches and consumptions available. On that basis, the grid modelling exercise can be repeated 8760 times in order to create a view on how the network will be loaded during a full year and identify potential overloads or congestions.

An integrated grid model of this power system, including the electrical parameters of all equipment, has to be set up. This model, coupled with nodal load and generation values at a specific point in time, allows the physical behavior of the power system at that point in time to be evaluated: either in normal state or in case of maintenance or contingencies (N-1 criteria). In any case, the network security of supply and reliability should be preserved.

With increasing penetration of distributed generation at DSO level, reverse flows can be expected from lower to higher voltage levels, leading to congestion. Therefore, the grid modelling architecture sometimes needs to be extended to lower voltage levels to assess grid security properly: thousands of lines, transformers and nodes may then need to be managed for each of the 8760 yearly studied point in time.

In order to reduce the complexity of the problem, a balance between model size and number of hours to be simulated can be found. Instead of modelling 8760 hours, a set of representative points in time can be selected (i.e. between 10 and 12 representative hours) based on clustering techniques in order to reduce the simulation time and data volumes to handle, while minimizing the approximation error [9].

For each selected point in time, reliability criteria (permissible limits or acceptable ranges) are set for a series of parameters:

- The quantities characterizing the flows on the network, namely the currents;
- The voltage level at each node of the network;
- Short circuit power level.

Moreover, an increasing integration of renewables leads to less fossil fuel generation, whereas these are key for today’s stability of the system, and consequently lead to new specific constraints on system operations. Therefore, for each representative point in time or at least the most severe ones, attention should be given to voltage stability, static and dynamic stability. In some cases, some dedicated assets (e.g. synchronous compensators, capacitors, SVC etc.) may be required to mitigate the detected reliability issues.

D. Cost-benefits analysis

Once some reliability issues have been identified during the grid studies, new grid infrastructure should be built to ensure that the reliability criteria are maintained.

Several options should always be investigated to challenge the solution and to avoid missing out on identifying the best approach. These options should also be communicated transparently to stakeholders to increase acceptance of the choice made. The various options can be designed on the basis of different architectures (e.g. meshed vs radial), different locations, different routes, different technologies (AC vs DC, overhead vs underground), voltage levels, different ratings, or

type of solutions, investing in transmission, distribution demand side management, storage and so on.
The needs can sometimes be clustered in a specific area to identify synergies between needs (demand increase, RES integration, replacement etc.) and shape the best grid architecture of the future.

The costs and benefits of each option should be compared to identify the solution whose benefits outweigh its costs the most. This requires an initial costing of the options, at this stage based on standard costing. The benefits can be derived from the grid and market studies and consist of a combination of several characteristics; e.g. increase reliability by avoided load curtailment, avoided (cost of) re-dispatch to address congestions and or curtailment of RES due to lack of capacity. The approach aims at comparing the cost with a list of complementary benefits, which may be monetarized [10]. Finally, all the benefits can be aggregated in one single value.

Beside the technical value of each option, one important aspect is its robustness toward plausible scenarios. An option addressing shortcoming of several scenarios will be more attractive to insure a future-proof network development.

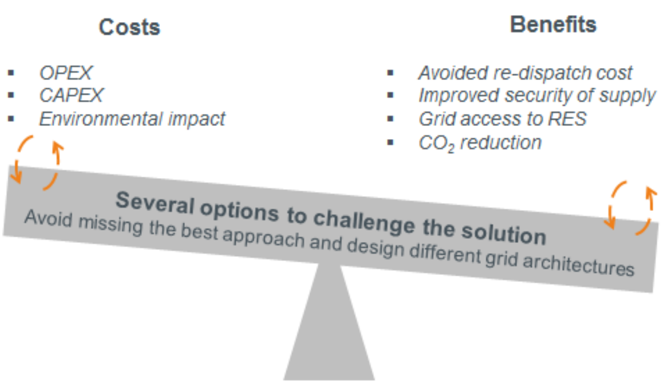

Fig. 5. Illustration of a cost-benefit analysis (CBA)

Environmental impact, including visuals, noise, electromagnetic fields, etc. must be included in the comparison of the options. These elements are important to the public and external stakeholders. They are key to transparently engage them on investment decisions.

E. Leveraging the value of the existing and future fleet

The zero-marginal cost of RES generation is lower than the marginal cost of fuel-based power plants (e.g. gas-fired power plants). Except for balancing purpose, the dispatching of the fuel-based fleet will decrease with increasing RES generation. The market shares and profitability of the conventional fleet will decrease accordingly, in an energy-only market.

The market modelling methodology as described above is a powerful tool to quantify the evolution of the economic parameters of the existing fleet while the share of RES evolves in the power system.

Furthermore, if the market model is extended to neighboring countries, the market analysis can highlight differences in electricity costs in the region and electricity exports possibilities towards neighbors. These exports can offer new market shares for Saudi's RES and conventional generation as well as growth opportunities for relevant system operators.

F. Portfolio management of grid investment

The definition of scenarios on the future evolution of the electricity sector is a powerful tool to frame uncertainties. The company's portfolio of grid investment can then be developed to be robust towards the defined scenarios and compliant to the relevant regulations and the company strategy. The investment portfolio is usually made of:

- Robust projects, which can be started for implementation and which demand for minor monitoring;
- Scenario-dependent projects which are condition-dependent. They will be achieved when a specific condition is fulfilled (e.g. confirmation of demand increase, of connection request etc.). These project may be started, e.g. for engineering and permits granting, but their actual realization is submitted to a final decision.

1) Steering of the investment portfolio

As time goes by, the investment portfolio is steered on a regular basis to include:

- New information on made hypotheses (e.g. about new demand forecast, new connection request etc.);
- Progress or delay in engineering or in the permits granting procedures, affecting the planning of projects;
- The available resources, both financial and human;
- Newly-identified projects.

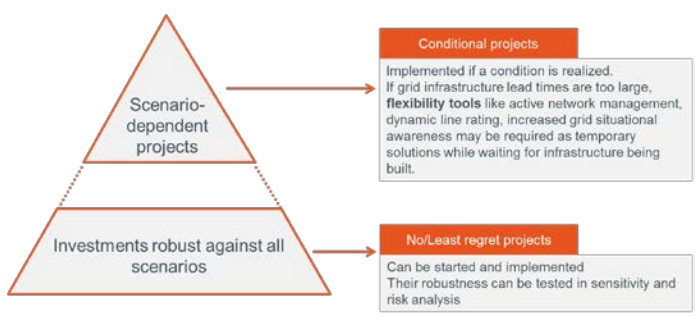

Fig. 6. Flexibility and robustness in portfolio management.

Some management decision may be needed to adapt the portfolio, e.g. hasten or postpone projects, cancel or develop new projects etc. In an uncertain future, risk metrics must be derived from the market and grid modelling to support the decision making process and limit the consequences in case of adverse decisions. For each project, risk management should be applied to assess and balance:

- The load at risk if the investment is postponed or cancelled;
- Potential generation re-dispatched if the investment is postponed or cancelled;
- Increase of market price or generation profitability if the investment is postponed or cancelled;
- Liabilities towards external stakeholders (e.g. grid users or public authorities) if the investment is postponed or cancelled;

- The investment cost saving if the investment is postponed; and
- The impact on other interdepending projects if cancelled or postponed.

2) *Bringing flexibility to the process*

Due to the long lead time to build new grid infrastructure, (typically two to ten years), the investment decisions should sometimes be taken before the underlying investment hypotheses are fulfilled.

In the case of new or increasing demand or generation of grid users, grid infrastructure should be built anticipatively, taking into consideration the:

- Technical design (where to build the capacity, what rating etc.) without any firm information about the change of demand and generation; and
- Risk of stranded assets if the generation or demand-change does not materialised.

In some cases, a chicken-or-egg dilemma may arise. The transmission operator shall not invest in grid capacities without any firm commitment of grid users, to avoid unnecessary costs. And grid users shall not commit to anything before being sure that the adequate grid capacity will be delivered in due time and that their grid access is not blocked.

New approaches, like "Active Network Management", can be developed to unlock the situation and facilitate the development of grid users' projects. Unlike the usual fit-and-forget approach, where a permanently N-1 secure connection is built for each grid user, leading to little grid management activities during the day-to-day operations, an active management scheme requires to monitor continuously real-time grid conditions and to adapt – perhaps - limit - grid users access, to keep the power system secure. In other words, the grid user usually has access to the grid except when the grid conditions are adverse. [11]

This active scheme enables quick access to the grid for grid users, with limitations in some cases, while waiting for the needed N-1 secure grid infrastructure to be built.

Such approach needs an enhanced grid situational awareness in the system control room, including better visualization of power system states, better assessment of operation boundaries, better forecasts of the grid users' impact on the system operation and much more. Dynamic line rating typically fits this approach to assess most accurately the capacity of overhead lines as a function of weather conditions and actual loading. In the near future, the decreasing cost of storage batteries will open new possibilities to increase the flexibility around infrastructure developments, postpone them or even cancel them.

III. Implementation Challenges

The implementation of such a holistic process often requires a re-engineering of the existing processes. The most impactful changes are:

- Moving from one future scenario to several scenarios coupled with periodic adjustments;
- Transparency and advanced quantitative analytics (e.g. cost-benefits analysis) to support the decision-making process; and
- A risk-based approach to steer the investment portfolio and limit damage in case of adverse decision.

The introduction of such a new approach should be supported by specific change management. The whole process should be governed by cross-functional committees, ensuring the buy-in and the constituency of the decisions made.

The process is complex and the information on project information (progress, budget and schedule), hypothesis on demand and generation, data and models need to be updated periodically. As the complexity of the modelling increases and the numbers of projects in the investment portfolio rises, dedicated advanced IT-tools are necessary to support the operational implementation of this methodology.

Fig. 7. Periodic steering of investment portfolio.

IV. Examples of Application

The proposed methodology has been applied within the Elia Group, both for their internal grid strategy and to define their development plans as approved by the Ministry [12][13]. Scenario-based grid planning is also applied at ENTSO-e, the association of European transmission system operators for electricity for the Ten-Year Network Development Plan [14][15].

V. Legal and Regulatory Considerations

The KSA generating capacity is around 66 GW in total at present, split forty-sixty between oil and gas. While future growth is difficult to predict with certainty, peak electricity demand is expected to increase sharply in coming years.

The ambitious Vision 2030 aims to reduce Saudi Arabia's dependence on oil, diversify its economy, and develop public service sectors [16]. Part of this vision involves the introduction of renewable energy as a major component of the Kingdom's energy mix. KSA has set itself an aggressive renewable energy target of 3.45 GW by 2020, with a further 6 GW envisioned by 2023.[17]

In line with the Vision 2030, there has been an increase in large scale developments in KSA, including the following four giga-projects:

- The Red Sea Project was announced in July 2019. It is a megaproject comprising the development of 14 luxury hotels, marinas, an airport and lifestyle amenities.[18] It is anticipated to increase KSA's gross domestic product by 5.86 billion USD1 and is being developed with a commitment to achieving 100% carbon neutrality. [19]

- The NEOM Bay project, estimated in value to exceed 500 billion USD, comprises high-end hotels and residential villas, as well as home, lifestyle and tourist facilities.[20] It is anticipated to commence development this year and boasts a target of running on low-cost regenerative energy.[21]
- The Qiddiyah project, focusing on entertainment;
- The Amaala project comprises 3,800 km featuring multiple luxury hotels, 200 retail establishments and 700 villas. The project is planned to be solely powered by renewable energy. [22]

The scale of these projects means a significant power generation requirement will be created, in a region of KSA devoid of grid infrastructure which in turn will require foreign investment in and expansion of the grid network.

In addition, traditional renewable energy streams, KSA has plans to diversify its REN sources and has projected 17GW of nuclear capacity by 2040 to provide 15% of the region's power via through nuclear generation. To this end, plans to develop two large nuclear reactors have been released. In pursuance of this objective, a body to govern the nuclear sector The Nuclear and Radiation Control Authority has recently been established pursuant to the Nuclear and Radiation Control Authority Law, issued by Council of Ministers decision No. 334 dated 25/6/1439 AH. [23]

In 2010, the King Abdullah City for Atomic and Renewable Energy (K.A.CARE) issued plans to foster KSA's development of industries related to renewable and atomic energy for peaceful purposes. Its goal is to raise the standards of living and quality of life in the Kingdom. K.A.CARE supports scientific research and development activities, to localize technology in its fields of specialization, and identity and coordinate the activities of the scientific research institutions and centers in the Kingdom in this field. Among other things, K.A.CARE determines priorities and national policies in the field of atomic and renewable energy in the Kingdom of Saudi Arabia in order to build a scientific technical base the field of power generation and therefore will have a particular interest in grid planning assessment and development.

The Saudi Electricity and Cogeneration Regulatory Authority (ECRA) is the governing body that regulates and governs the electricity and water sectors. ECRA was established pursuant to Council of Ministers Resolution No. (236) of 27/8/1422 AH to regulate the electricity and water desalination industry in KSA in order to ensure provision of adequate, high quality and reliable services at reasonable prices. ECRA monitors the performance of the service providers within a regulatory framework, in accordance with government laws, regulations, policies and standards as well as international best practices in order to guarantee the provision of safe, reliable, reasonably priced and efficient electric power and desalinated water to the consumers of Saudi Arabia.

Under the Electricity Law issued by Royal Decree No. M/56 20/09/1426H of 22 November 2005 and the ECRA Charter, ECRA's is responsible for four key areas, which are relevant for grid planning as indicated below:

- Supply Matters: issuing licenses for generation, transmission, distribution, retailing and trading of electricity and cogeneration services; monitoring licensees' compliance with their license requirements and conditions; development of unified regulatory accounting and reporting procedures for industry providers; coordination of the infrastructure and the development of any expansion plans within these industries.
- Consumer Issues: assessment of tariffs charged for supply of electricity, cogeneration, and water desalination services, periodic review of these tariffs, proposing (as needed) any new tariffs to the government, protecting relevant stakeholder interests, investigating and resolving complaints by involved parties, and improving industry performance.
- Technical Issues: developing and issuing best practice codes and standards, ensuring adequacy of any industry specific research and development activities, promoting energy conservation measures in coordination with the Ministry of Energy and the Ministry of Environment, Water and Agriculture, and any other relevant technical matters.
- Organizational and Administrative Tasks: to define the public interest in the electricity and water desalination industry, develop regulations for the expansion of relevant infrastructure, encouraging private sector participation and investments in cogeneration, and issuing periodic reports to the Council of Ministers on relevant costs and tariffs.

The Electricity Law and the ECRA Charter state that the following activities may only be carried out after first obtaining a valid license from ECRA.

- Generation, transmission, distribution, trading, retail, export or import of electricity;
- Cogeneration or trading in cogeneration products; and
- Water desalination, its transportation to the points of distribution, or trading in desalinated water.

Unlike the other GCC states, there is presently no common grid system between KSA and its neighboring countries. Successful integration of RES in KSA will be largely dependent on the integration of the existing regulatory framework with energy produced by new technologies as they develop to ensure coherence in electricity laws. KSA is unique in the region in having 60 Hz grid frequency, which severely limits the potential for cross border grid interconnections – it has no electricity import or export. A practical recommendation when developing the RES regulatory framework is to ensure that it provides effective grid balancing systems, which facilitate transmission of uniform voltage and eliminate energy loss.

A recent legal development is the recent issuance of the Small-Scale Solar PV Systems Regulations No. ERD - TA – 021 (V01/17) issued by the administrative decision No (182) dated of 4/11/1438 H of 28/7/2017.
Although the intended scope of these regulations is somewhat unclear, it appears to provide the regulatory framework for the connection of a small-scale solar PV systems to the KSA distribution system, and will apply to the Distribution Service Provider (DSP) (currently, only the Saudi Electricity Company), any eligible consumer, certified consultant or contractor, and any other persons involved in the connection of such systems to the distribution system and/or entering into a net metering arrangements with the DSP. Thus these regulations are also relevant for future grid developments.

In conclusion, one of the key barriers to achieving KSA's low-carbon goals KSA is the absence of a robust legal framework governing alternative energy supply and generation thus far. We consider the implementation of a sound regulatory and support framework by ECRA, assisted ably by K.A.CARE, provide a sensible basis for the expansion of the electricity grid in KSA. This is consistent with Saudi's Vision 2030 and its goal of a diversified economy, which is expected to increase its local energy consumption threefold by 2030. KSA has obvious solar and wind power potential, and its plans for the expansion of its renewable energy sector [2], though beyond the scope of this article, are impressive. There is much to look forward to.

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VII. Biographies

Fabian GEORGES has joined Elia Grid International (EGI) as the Head of Grid Development, Markets & Regulation. Prior to joining EGI, Fabian held different positions within Elia - the Belgian Transmission System Operator - related to strategic grid planning, investment portfolio management, RES integration, modelling (risk, market, security of supply), cost-benefits analysis and European collaboration for the development of cross-border interconnections. Fabian holds a Master of Science in Electrical Engineering from the University of Louvain (*Université Catholique de Louvain - UCL*) as well as a Master in Management from the same university. Fabian has attended programs at the Vlerick Business School and Florence School of Regulation.

Dr. Aymen CHAOUACHI is a Power System Operation and Security expert at Elia Grid International (EGI). Prior to joining Elia Group, he worked for Hitachi Ltd. in Japan as a Research and Development Engineer and the European Commission as Scientific Officer mainly involved on Energy security of supply, smart grids and RES integration. Aymen holds a PhD in Electrical Engineering from Tokyo University of Agriculture and Technology (TUAT), Japan. He has more than ten years' experience in Renewable Energy Sources (RES) integration and operation.

Dr. Georgios PAPAEFTHYMIOU is a Senior Power System Operation and Security expert at Elia Grid International (EGI). He holds an MSc. on Power Engineering with focus on High Voltage equipment, and a PhD in Integration of variable renewables in power system operations and planning. He has 14 years experience on technical, economic and policy aspects related to the future development of power systems and power markets. He has worked in a wide spectrum of topics including power grid design and power system security impacts from RES and DER, power system flexibility, power market design and policy.

Isabelle Gerkens is a Senior Expert in Energy Market, Legal & Regulatory aspects at EGI. She holds several LLMs in law, used to work as a lawyer, a compliance officer and an Electricity Grid Concepts & Contracting Development Expert. She has more than 20 years of experience in legal, contractual and regulatory aspects of transmission sector as well as liberalization of electricity markets. She is an expert in design of market mechanisms and connection and access products used by TSOs and their grid users. Isabelle is experienced in the drafting and implementing national grid codes in Belgium, EU Network Codes and the Operational Handbook, as in 2011 – 2015 she worked as senior expert in the units Belgian Grid Concepts as well as Codes, Contracts and Power Quality and is currently working on the proposals for the modification and update of EU Network Codes.

Rita Allan is a senior associate in the Dubai office of Pinsent Masons LLP, an international law firm. She specializes in large scale international construction and infrastructure projects in a wide range of sectors including energy, renewables, petrochemicals, water, transportation, healthcare and education. Rita has an indepth knowledge of the regional power market, having advised on a number of independent power projects in the Kingdom of Saudi Arabia and elsewhere in the GGC. Rita has assisted clients with the entire tendering process, contract negotiations and project financing, along with post completion issues such as variations, refinancing and disputes. She is experienced in drafting, reviewing and negotiating a wide range of commercial contracts and agreements throughout the procurement and execution phases of a project, and regularly acts for contractors, funders, developers, employers, and consultants in the Middle Eaast and worldwide.

Ibrahim Alajaji is a partner at Al Sabhan & Al Ajaji Law Firm in Riyadh, Saudi Arabia. He is the head of the firm's corporate practice and concentrates his practice on corporate, M&A, joint ventures, labor law, islamic finance, real estate and litigation matters. Ibrahim received his law degree from the University of Amman in Jordan and is a member of the Saudi Bar Association. Ibrahim has been recommended by the Legal 500 in 2017 and 2018 as an expert in Construction and Real Estate law. Ibrahim has practiced in KSA since 2003. He has acted for many government ministries, government-owned master developers, infrastructure projects, foreign and locally owned sub-developers, hotel operators/owners, property funds, international investors and assists corporations with their construction and real estate development requirements.