Paper 2169
Electricity Markets

Exploring Contractual Arrangements for Electricity Trading in the Middle East

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SUMMARY

The Gulf region is undergoing an energy transition, and the electricity sector is crucial to its success. Since 2001, the region's interconnections have allowed electricity trade among the Gulf Cooperation Council (GCC) countries. Its continued interconnection expansion within the GCC and Middle East and North Africa (MENA) region, joint planning and operations, and market integration can accelerate energy sustainability, reduce costs, enhance the global energy competitiveness of GCC countries, and improve resiliency and reliability.

A growing literature analyzes electricity trading in the GCC and broader MENA region centring on the feasibility of electricity trading, the impact of fossil fuel subsidies on the amount of trading, expanding renewable electricity generation and achieving significant reduction, if not elimination of carbon dioxide emissions in the power sector. Even though hourly market coupling is not yet on the region's agenda, the literature focuses mainly on that type of agreement to assess the benefits of regional electricity trading. This paper proposes to complement the existing literature on the GCC and MENA by evaluating other types of electricity trading mechanisms that could be more realistic within the region.

This paper aims to explore how electricity trading arrangements could be developed in the GCC countries plus Egypt, Jordan, and Iraq. Within that geographical context and at a 2030 horizon with a higher penetration of renewable sources of electricity, it uses the example of the interconnexion between Egypt and Saudi Arabia to quantify the benefits of several contractual trading schemes. Specifically, it considers day-ahead market coupling with hourly contracts but also long-term contracts with different time granularities.

The obtained results show that the interconnection between Saudi Arabia and Egypt is used in both directions, suggesting the importance of well-defined long-term arrangements. Then, we test and assess different contractual trading schemes between Saudi Arabia and Egypt. The results show that a fixed and constant flow by month can bring only 10% of the value of that border, whereas other contractual profiles with more granularity in time can significantly increase the economic value.

The paper goes forward than the classical cost analysis based on a dispatch tool. To leverage the benefit of the digitalization of the power sector, it also discusses the importance of developing advanced forecasting tools. Finally, it proposes recommendations for the implementation and governance of highly efficient electricity trading scheme in the GCC and MENA.

KEYWORDS

Electricity – Trading – Interconnection – System – GCC

1. INTRODUCTION

While the Gulf Cooperation Council (GCC) countries and the broader Middle East and North Africa (MENA) region have historically relied on national fossil-fuel resources to generate electricity, the overall region is on a pathway to transition to renewable energy sources of electricity. Since 2001, the region's interconnections have allowed electricity trade among the Gulf Cooperation Council (GCC) countries. Its continued interconnection expansion within the GCC and Middle East and North Africa (MENA) region, joint planning and operations, and market integration can accelerate energy sustainability, reduce costs, enhance the global energy competitiveness of GCC countries, and improve resiliency and reliability.

The benefits of cross-border electricity trading have been largely identified in the literature. It can bring cost-savings by reducing unserved energy, decreasing variable generation costs, lowering the costs of ancillary services, and avoiding/deferring investment in generation [1]. When renewables account for a significant share of the generation mix, developing internal networks or interconnectors between countries also has the benefit of reducing the curtailment of renewable energy [2, 3]. Developing more interconnectors can constitute a cost-effective option to reach very high penetration of renewables [4]. Similarly, interconnectors can also play a role in reducing greenhouse gas emissions [5,6].

This paper aims to explore how electricity trading arrangements could be developed in the GCC countries plus Egypt, Jordan, and Iraq. Within that geographical context and at a 2030 horizon with a higher penetration of renewable sources of electricity, it uses the example of the interconnexion between Egypt and Saudi Arabia to quantify the benefits of several contractual trading schemes. To do so, a bespoke network constraint economic dispatch model for considered region is used to analyze the implications of cross-border electricity trading on variable generation costs, the curtailment of renewable energy, and emissions. Several types of electricity trading schemes are considered, from day-ahead market coupling with hourly contracts to long-term contracts with different time granularities.

In addition, this paper also proposes to go further than the economic assessment of electricity trading. After a first quantification is done based on a classical dispatch tool, the paper discusses how forecast errors should be accounted for in practice and proposes to develop an advanced forecasting tool based on state-of-the-art Machine Learning approaches. In doing so, we explore how digitalization of the power sector could be leveraged to improve the efficiency of cross-border electricity trading in the GCC and MENA. Finally, the last section proposes avenues for the implementation and governance of electricity trading in the region based on the new capabilities offered by digitalization.

2. ANALYSIS OF POTENTIAL LONG-TERM BILATERAL AGREEMENTS FOR ELECTRICITY TRADING BETWEEN EGYPT AND SAUDI ARABIA

Based on a quantitative approach, this section illustrates to which extent the economic value of a long-term arrangement is influenced by the volume's profile defined in the contract. We take the future 3 GW interconnector[1] between Egypt and Saudi Arabia as an example for our discussion.

[1] The 3GW HVDC interconnector between Egypt and Saudi Arabia is currently under construction and is expected to be commissioned by 2026. It consists of a HVDC line with a length of 1,300 km between Cairo (Egypt) and Tabuk (Saudi Arabia) and Madinah (Saudi Arabia). The estimated cost of the project is US$ 1.8 billion. See [8].

To do so, this section conducts an analysis based on a classical approach consisting of the simulation of hourly dispatch for the GCC+ region. Specifically, we used the hourly dispatch model presented in [7] and which includes Saudi Arabia and eight neighbouring countries as shown in Figure 1. This model corresponds to a classical formulation of the dispatch as a cost-minimization problem and is implemented in the commercial software PLEXOS.

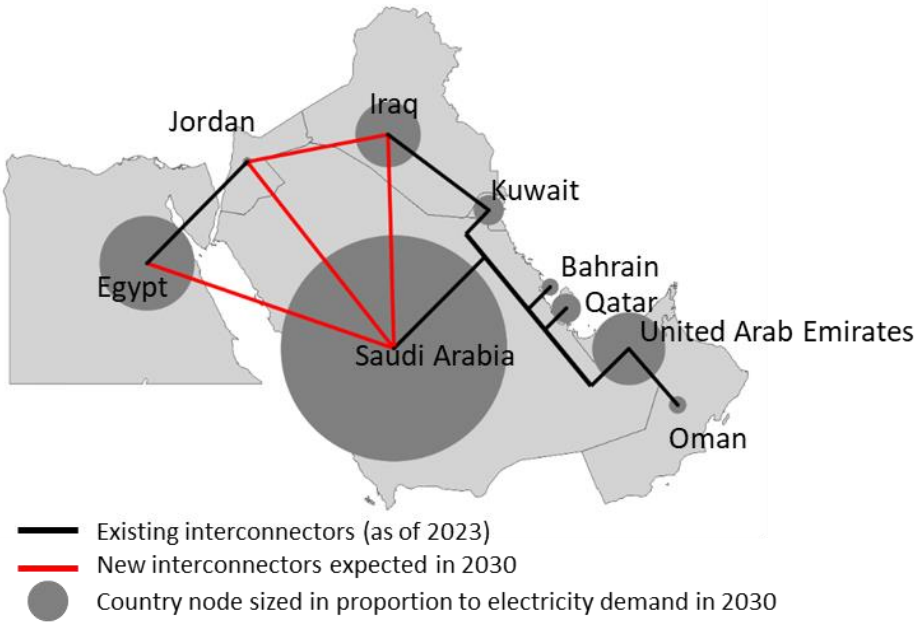


Figure 1. Geographical perimeter of the model and interconnectors between countries.

The hourly dispatch model is used to define and assess different types of bilateral agreements for electricity trading between Egypt and Saudi Arabia. Figure 2 presents the approach used to assess the performance of bilateral agreements for electricity trading. First, we run the hourly dispatch model under hourly market coupling, i.e., we let the model optimize the hourly dispatch in each country as well as the hourly flows on each interconnector. Second, we use the flows obtained for the interconnector between Egypt and Saudi Arabia to define the profile of each contract. Third, we run the hourly dispatch under the contract conditions, i.e., the flow between Egypt and Saudi Arabia is fixed as per the contract's profile. Finally, we analysis the outcomes of the contract and compare the performance of each contract.

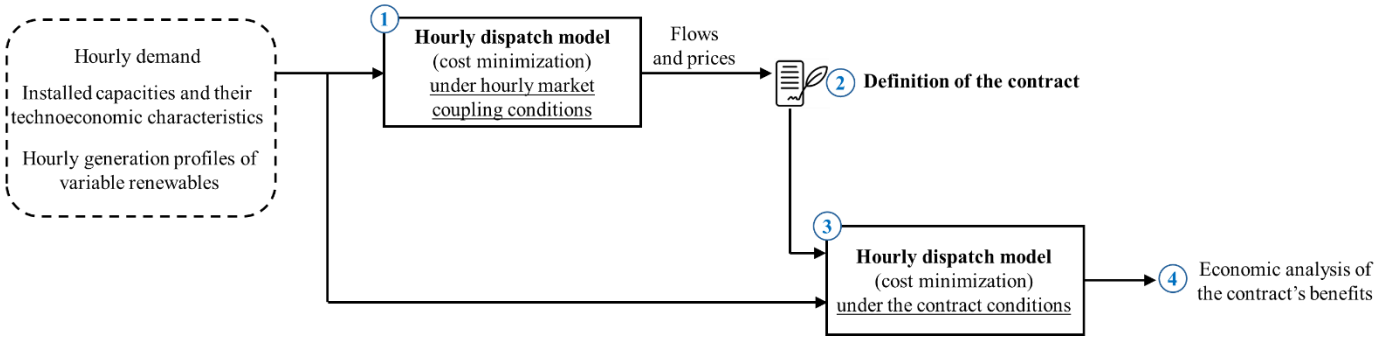


Figure 2. Overview of the approach to assess bilateral agreements, based on a dispatch tool.

It is important to note that we use our modelling framework in the context of perfect foresight, i.e., we assume that the forecasts used to define the contracts are identical to the realizations.

This deterministic approach results in an optimistic performance assessment of the bilateral electricity trading. This approach and the ways forward are discussed at the end of the section.

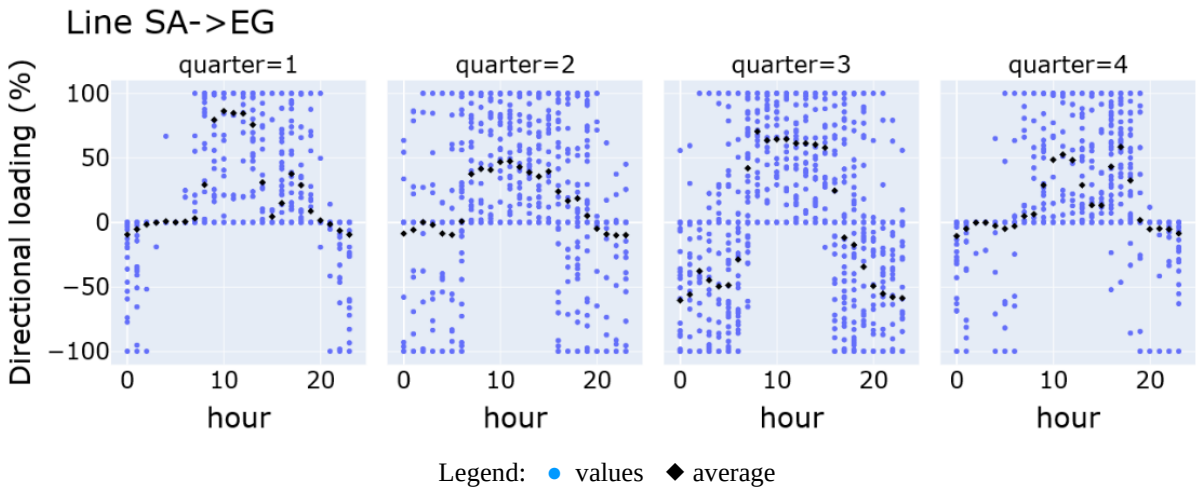
Table I summarizes the different runs performed and presented hereafter.

Table I. Description of the scenarios.

Scenario name (abbreviation)	**Description**
Hourly trade (HT)	The complete system with nine countries is performed with optimal hourly electricity trading between countries.
Hourly trade with no flows between Egypt and Saudi Arabia (HT_noEG-SA)	Identical to the HT scenario, but the flow between Egypt and Saudi Arabia is fixed at zero. This scenario is used to estimate the value of the trade between Egypt and Saudi Arabia.
KSA-EG long-term contract (4 scenarios)	Based on the HT scenario but flows between Saudi Arabia and Egypt are fixed as inputs. Four different contractual profiles are tested. **SA-EG_fixed_month**: a fixed profile defined for each month. **SA-EG_fixed_week**: a fixed profile defined for each week. **SA-EG_daily_quarter**: a daily profile defined for each quarter. **SA-EG_daily_month**: a daily profile defined for each month.

2.1 Overview of the flows between Egypt and Saudi Arabia in the context of hourly market coupling

Figure 3 displays the scattered plot of the directional loading on the interconnectors for each quarter of the year 2030, with the hours of the day shown on the x-axis. The dark markers indicate the average loading for each hour. It shows that Saudi Arabia imports electricity from Egypt, Jordan and the GCCIA mainly at night during the third quarter (July, August, and September). It also shows that throughout the year, Saudi Arabia exports electricity to Egypt during the day and imports it from Egypt at night.



Note: The first quarter corresponds to January, February, and March. The second quarter corresponds to April, May, and June. The third quarter corresponds to July, August, and September. The fourth quarter corresponds to October, November and December. EG= Egypt; SA=Saudi Arabia.

Figure 3. Directional loading on the line between Egypt and Saudi Arabia.

To understand the root causes of this trend, Figure 4 displays the average hourly electricity prices in Egypt and Saudi Arabia. During the day, the Saudi price decreases due to its PV generation, thus allowing Egypt to import electricity from Saudi Arabia. During the night, both Egyptian and Saudi prices align with the marginal costs of gas-fired generation units. During the third quarter (July, August, and September), Saudi Arabia faces higher demand and needs to use gas steam turbines, with a variable cost of 77.5 US$/MWh at night, whereas the Egyptian main marginal unit remains gas-combined cycle (CC) at night, with a variable cost of 56.5 US$/MWh.

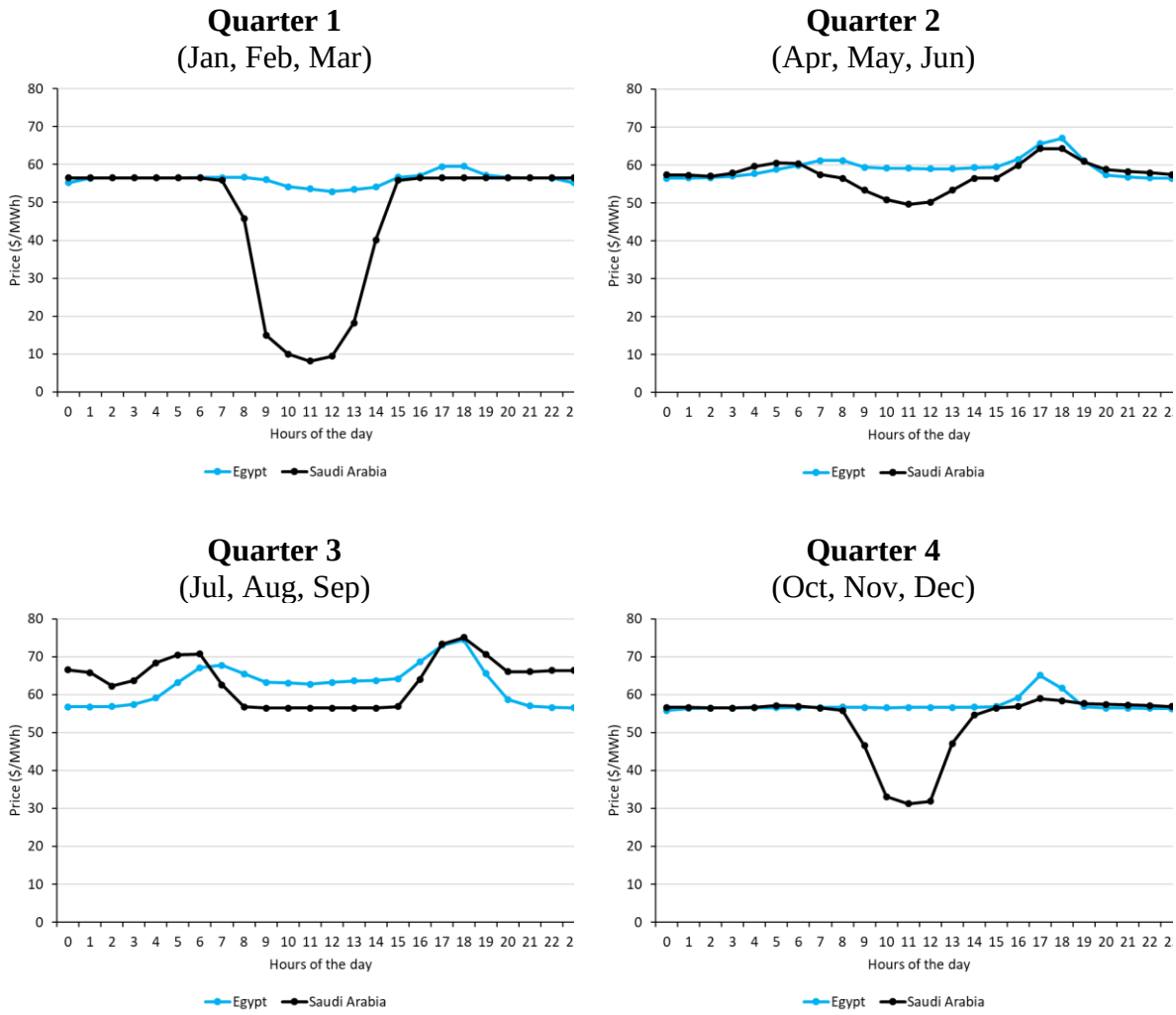


Figure 4. Average hourly electricity prices by quarter in Egypt (in blue) and Saudi Arabia (in black) in the HT scenario.

2.2 Maximum economic value of the Saudi-Egyptian interconnector

To estimate the economic value of the Saudi-Egyptian interconnector, we compare the **HT** scenario to the **HT_noEG-SA** scenario where no electrical flow is allowed between Saudi Arabia and Egypt. This scenario allows us to quantify the maximum economic value of the interconnection, which is obtained for day-ahead market coupling with hourly contracts between the two countries.

When no electricity flow is allowed between Saudi Arabia and Egypt, the total variable generation cost for the nine countries increases from US$ 66,366 million (**HT** scenario) to US$ 66,576 million (**HT_noEG-SA** scenario). This indicates that electricity trading between Saudi Arabia and Egypt can bring a maximal value of US$ 210 million in 2030. Recall that this value corresponds to the variable generation costs only, but additional benefits can be achieved in the longer term when investment decisions are considered. In the case of hourly electricity trading

(**HT** scenario), the congestion rent[2] of the line between Saudi Arabia and Egypt adds up to US$ 171.41 million in 2030 for an annual flow of 8.8 TWh (both directions included).

2.3 Long-term contractual arrangements

We investigate alternative bilateral contractual arrangements between Saudi Arabia and Egypt and estimate the economic benefits of both types compared to the maximal benefits of US$ 210 million in 2030, achieved with day-ahead market coupling with hourly contracts. We define four types of long-term contracts for electricity exchange between Saudi Arabia and Egypt as follows:

- **SA-EG_fixed_month**: A fixed profile defined with monthly granularity: for each month, the flow between Saudi Arabia and Egypt is defined to correspond to the equivalent net flow of the hourly simulation.

- **SA-EG_fixed_week**: A fixed profile defined with weekly granularity: for each week, the flow between Saudi Arabia and Egypt is defined to correspond to the equivalent net flow of the hourly simulation.

- **SA-EG_daily_quarter**: A daily profile defined for each quarter: for each quarter, we define a typical daily profile at an hourly timescale, which corresponds to the average profile observed during the same month in the hourly simulation.

- **SA-EG_daily_month**: A daily profile defined for each month: for each month, we define a typical daily profile at an hourly timescale, which corresponds to the average profile observed during the same month in the hourly simulation.

All types of contracts keep the net electricity exchange between Saudi Arabia and Egypt unchanged. However, the annual export and import volumes between the two countries differ for each type of contract scheme as presented in Table II. The daily profile with monthly granularity (**SA-EG_daily_month** scenario) makes export and import volumes more representative of the hourly trading.

Table II. Electricity flows between Saudi Arabia and Egypt for the different contractual arrangements.

	Annual export from Saudi Arabia to Egypt (TWh)	**Annual export from Egypt to Saudi Arabia (TWh)**	**Net exchange from Saudi Arabia to Egypt (TWh)**
SA-EG_fixed_month	3.8	0.5	3.2
SA-EG_fixed_week	4	0.8	3.2
SA-EG_daily_quarter	5.3	2.1	3.2
SA-EG_daily_month	5.4	2.2	3.2
HT	6	2.8	3.2

To assess the benefits that could be achieved by the different contractual schemes between Saudi Arabia and Egypt, Table III presents the total variable generation cost for the entire perimeter of our model, which comprises nine countries. It shows that defining a fixed profile

[2] The congestion rent is defined as the difference between Egyptian and Saudi prices multiplied by the flow on the interconnector and summed up for all hours of the year. Losses are not considered in the congestion rent.

by month (**SA-EG_fixed_month** scenario) or week (**SA-EG_fixed_week** scenario) brings a benefit of only US$ 26-33 million, which corresponds to 12%-16% of the maximum value of the interconnector. Alternatively, defining a daily profile for each quarter (**SA-EG_daily_quarter** scenario) or each month (**SA-EG_daily_month** scenario) increases the economic benefits to US$ 112-122 million, representing 54%-58% of the maximum value of the interconnector. This justifies the interest in developing well-designed bilateral contractual arrangements as a compromise solution between having no trade and having full day-ahead market coupling with hourly contracts. These estimates are nonetheless optimistic because, in practice, uncertainty about the contractual profile, which must be defined significantly ahead of delivery, could reduce the value brought by long-term contracts.

Table III. Total variable generation costs and their associated benefits for the four different contractual arrangements between Saudi Arabia and Egypt.

Scenario	**Total variable generation cost (million US$)**	**Gain associated with the SA-EG interconnector (million US$)**	**% of the maximum value**
HT_noEG-SA	66,576		
SA-EG_fixed_month	66,550	26	12%
SA-EG_fixed_week	66,543	33	16%
SA-EG_daily_quarter	66,463	112	54%
SA-EG_daily_month	66,454	122	58%
HT	66,366	210	100%

To complement the cost analysis, Table IV provides the curtailment of renewable energy and CO_2 emissions for the four contractual arrangements considered. It shows that both curtailment and emissions are negatively impacted when long-term arrangements are used compared to hourly market coupling. Specifically, the fixed contracts (**SA-EG_fixed_month** and **SA-EG_fixed_week** scenarios) show worse results, with an increase of 17% and 0.3% in the curtailment of renewable energy and emissions, respectively, compared to the **HT** scenario. The contracts with a daily pattern (**SA-EG_daily_quarter** and **SA-EG_daily_month** scenarios) perform better, with an increase in renewable energy curtailment of only 6%-7% compared to the **HT** scenario, and additional emissions of 0.7 million tCO_2.

Table IV. Curtailment of PV, wind and CO_2 emissions for the four different contractual arrangements between Saudi Arabia and Egypt.

Scenario	Total variable generation cost (million US$)	Curtailment of PV and wind (GWh)	CO_2 emissions (million $MtCO_2$)
SA-EG_fixed_month	66,550	10,465	500.2
delta w.r.t. HT	*+0.3%*	*+17.2%*	*+0.3%*
SA-EG_fixed_week	66,543	10,443	500.2
delta w.r.t. HT	*+0.3%*	*+17.0%*	*+0.3%*
SA-EG_daily_quarter	66,463	9,584	499.5
delta w.r.t. HT	*+0.1%*	*+7.4%*	*+0.1%*
SA-EG_daily_month	66,454	9,496	499.5
delta w.r.t. HT	*+0.1%*	*+6.4%*	*+0.1%*
HT	66,366	8,927	498.8

Note: w.r.t.= with respect to.

3. LEVERAGING DIGITALIZATION FOR CROSS-BORDER ELECTRICTY TRADING: ENHANCING FORECASTING PROCESSES

While the analysis presented previously relies on a classical dispatch tool, used in a deterministic manner, it is key to estimate how forecasting errors could affect the benefits of bilateral electricity trading agreements. To do so, we explore how the methodology used so far could be improved to include uncertainties due to forecast errors and how advanced forecasting technics could help reduce them. This section discusses digitalization concepts but its implementation and evaluation w.r.t. the previous case study is let for future works.

In practice, the contract's profile is to be agreed upon before realization occurs, e.g., the profile can be defined one month ahead. Therefore, the definition of the contract cannot rely on the realization that will occur but can only rely on forecasts of what will happen. Figure 5 presents how the previous approach should be updated to account for forecasting.

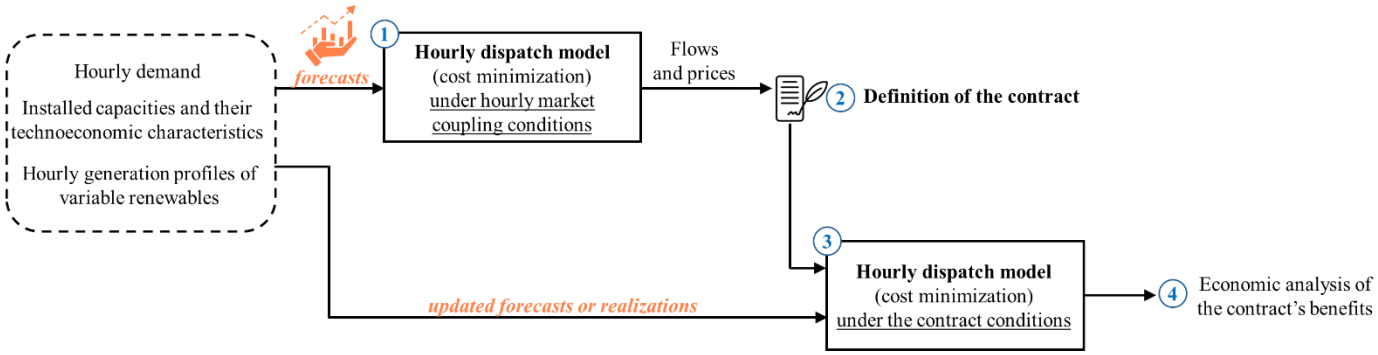


Figure 5. Accounting for forecasting in the assessment of bilateral agreement for electricity trading.

When done in practice, the definition of contracts' terms and performance are highly dependent on the quality of the forecasts performed within short term scales. Thus, it becomes key to use advanced and state-of-the-art forecasting technics that allow to adapt quickly to changes in customer load or demand, and/or weather and market conditions, for instance. Those technics are known to be part of the broad topic of digitalization.

Digitalization is the process of using information and communication technology, such as Internet of Things (IoT), cloud computing and intensive data exchange, smartphones, and smart embedded sensors, to create new products or services or enable major business improvements and new business models [9]. Digitalization is expected to have significant benefits and impacts on various sectors, including the power sector [10, 11, 12]. Specifically, power grids are undergoing a huge transformation towards digitalized and highly connected power grids equipped with a huge number of IoT enabled sensors and devices. These devices collect and transmit data in real-time on the power system (power generation, transmission lines, substations, distribution lines, energy storage) dynamics and status such as energy consumption, distribution/transmission lines voltage, load, temperature, frequency, generated energy, etc. The potential captured value of the data generated by these devices is significant since they provide high temporal and spatial resolution measurements about the power grid' status and dynamics.

Digitalization of power grids can contribute to maximize the benefits of the MENA region's interconnections by, for example, maximizing the use of variable renewable energy (wind and solar) through high accurate forecasting of power demand and generation at short term scales and the optimization of the use of transmission lines capacity. These benefits are obtained using a big set of historical and real-time data about the demand and generation patterns and dynamics as well as the transmission lines' thermal characteristics. In addition, advanced analytics and data processing using cloud computing enable to extract in almost real-time reliable and actionable insights about the power flows quantities and directions to achieve the best business and environmental profits.

In the context of this paper and given the approach detailed therebefore, we propose some leads on how to use power grid digitalization to maximize the economic and environmental benefits generated by electricity trading on the interconnexion between Egypt and Saudi Arabia. To this end, a forecasting model using cutting-edge methods (i.e., Machine Learning or Deep Learning) could be developed, with the assigned objective to predict the future value of an output[3], within a time horizon in response to a set of predictors or features. Predicting, at different time horizons, the electrical energy consumption or demand, the produced energy from renewable energy sources (e.g., wind turbines or photovoltaic panels), and the health state of transformers, generators, or transmission lines are examples of the use of prediction-based functions in a power system.

This could be achieved by proceeding with the following steps:

A. **Data collection, pretreatment and annotation.** The available data about the past consumption and generation is collected. This data provides information about the global consumption/demand at high temporal resolution, i.e., minutes, thanks to the use of smart meters. The data about the generation profile, in particular from weather-dependent resources, is also of high temporal resolution thanks to the use of high-resolution IoT enabled sensors. The collected data represent the consumption and generation during long period, from several months to several years. This data forms the training set. They provide different features that influence the consumption or generation, like for instance, the ambient temperature, sunlight irradiance, or the wind speed. Each data is annotated by the consumed or generated energy at each time step. This annotation represents the outcome or the target feature of the data.

[3] The predicted output is also referred to as "target variable".

B. **Model building to predict the consumption and generation for different time scales and with high accuracy.** The training set from step 1 is used to teach a model how to predict consumption and another model to predict the generation. Several supervised machine learning methods could be used to find the best combination of them allowing to draw the best from their diversity and provide the best prediction accuracy.
C. **Model test and improvement.** The built model from step 2 is used to predict the new incoming data at different time scales. The prediction error is then used to improve the prediction accuracy for the new arriving measurements. The provided predictions by the demand prediction model and the generation prediction model are used by the dispatch model (e.g., PLEXOS) as inputs to increase the accuracy and efficiency of its optimization.

This proposed framework could be integrated into the analysis provided in section 2 to account for forecasting error. It could also be deployed in practice in the implementation of bilateral agreements for electricity trading.

Additionally, digitalization could also be used to perform a data-driven and AI-enabled optimization by determining the actions that allow to minimize a cost function, and, in doing so, it could be an alternative to the approach based on dispatch tools. The latter is a mathematical representation of a set of criteria to be optimized while satisfying a set of conditions or constraints. These actions can be recommendations executed manually by end-users or automatically by automated controllers. For instance, the cost function can represent the predicted electricity prices with three constraints: the interconnection transmission line capacity, the predicted generation, and the predicted demand. The optimization outcome is the selection of the periods when to sell electricity, i.e. when electricity prices are high under the constraints of the available generation and cross-border transmission capacity.

4. THOUGHTS ON IMPLEMENTATION AND GOVERNANCE FOR EFFICIENT CROSS-BORDER ELECTRICITY TRADE IN THE CONTEXT OF A DIGITALIZED POWER SYSTEM

Once benefits of cross-border electricity trading are evaluated and acknowledged, its implementation road map and governance are key. While electricity trading has been established in many places across the world, we suggest that context-specificities and new available technologies should be carefully considered to ensure the implementation of efficient and tailored-to-the-context electricity trading scheme.

The current market model in both Saudi Arabia and Egypt relies on a single buyer which is the sole entity carrying out cross-border trading. Given this sector organization, the respective national transmission system operator, in coordination with the single buyer, appears as the responsible agent for cross-border capacity calculation and then allocation (i.e., ex-ante explicit allocation), as well as scheduling and balancing (all the more so with HVDC interconnectors).

However, this simplified organisation should not refrain initiatives to innovate for a more efficient organisation thanks to the use of new technologies and digitalization efforts, namely smart meters and artificial intelligence (AI).

The breakthrough brought by the digitalisation of the electricity sector spans over different fields like the power system operation from long to real-time, but also the trading activities. Power system and market oversight can also be improved by the proper use of the new

technologies. Leveraging flexibility capacities in both generation and load thanks to AI can lower total system costs and increase system reliability.

4.1 Data to serve the governance of the interconnected system

The governance of the development and use of interconnectors can benefit from new technologies, i.e. AI and smart meters, but also blockchains[4] and the associated tokens, that can help to improve the operational and economic efficiency of the interconnected system.

Operational efficiency

The current operational processes cope with the requirements to schedule flows ahead of delivery to ensure the security and reliability of the interconnected power system. They are performed sequentially at different time horizons.

Yet, comprehensive and reliable sets of data, impacting the load, the transmission infrastructure and the optimal generation mix, associated to AI can support the system operators in simplifying their operational processes and IT systems and be more accurate in their load and generation forecasts. Section 3 of this paper proposes some leads in this field.

AI and shared sets of data could enable the system operators in both countries to co-optimise their national power systems and better benefit from the flexibility of both the generation and demand. The adjustment of the flows and the flexibility of the scheduling process are instrumental for almost real-time optimization and decision-making. This co-optimization could be achieved with minimal implementation costs and changes in the current operational processes through the use of smart meters.

This could be valuable especially in the event of unplanned outages or equipment defaults, when quick adjustments are necessary. Interconnectors would show the most of their value in such situations.

Interconnected system planning and development

The collected data could also be used to make better-informed choices in the field of system planning, both for transmission and generation. This could help avoid under or over-investment in grid and generation and direct investment in certain types of technologies to support national and regional objectives in terms of energy policy.

Transparency, reporting and surveillance

Transparency is a fundamental element to foster energy trading. Transparency calls for efficient data collection and publication processes enabling a level playing field, i.e. a fair competition environment where all the market stakeholders access the same type and level of information pertaining to their trading activities at the same time. Automation of real-time data collection and publication thanks to smart meters and AI can enhance the quality of the decision-making processes of the market participants but also of the system operators.

Furthermore, power system and trading activities' oversight by National Regulatory Authorities (NRAs), and regional authorities (where applicable) could also be made easier through the use of technology, automation of tasks, and access to reliable data for analysis.

[4] IBM defines the blockchain as "a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network". See https://www.ibm.com/topics/blockchain

4.2 Smart contract for cross-border electricity trading

Smart contracts are applications that are being developed on the blockchain. They are not “contracts” but "self-executing" computer programs [13], whose function is to "automatically control digital assets": as soon as a certain condition foreseen by the programmer is fulfilled, and information reaches the program, the pre-coded computer consequence is executed.

In a nutshell, the term "smart contracts" is merely a metaphor, intended to express the automaticity of a program's ability to perform a computing function if the conditions are met. The key idea behind the concept of smart contracts is to guarantee the binding force of contracts no longer by law, but directly by computer code: "code is law" [14].

Data from smart meters gathered within a blockchain could be used to manage the access to and the use of interconnectors via “smart contracts” materialized by tokens, that record in an automated manner the flows, and then generate the billing information for the counterparties. Tokens ensure the tracking and reliability of embedded information such as energy flows or origin of energy (green attribute).

Besides, smart contracts could also ease the transfer of positions among the different users. It might not be so relevant for the time being, but the initiatives engaged in the GCC and MENA regions to attract new investors especially in renewables might encourage simplified process for cross-border trading, especially for the back-office of the new and existing players by decreasing transaction costs.

In the same way, and at a later stage, i.e. in a more competitive wholesale market with manyfold stakeholders with different trading interests (generators, consumers, suppliers, etc.), smart contracts can leverage the behaviours of the users of the power system and support the development of demand-response. Indeed, smart contracts can automate the adjustment of a load to a signal, being market prices or TSO’s orders for power system security and create an environment fostering the efficient use of power given overall (and local) power system constraint. Demand can therefore more actively participate in power system reliability and security and the price-elasticity of demand improve for a better economic efficiency of the power system. In a cross-border trading context, smart contract can also adjust the volumes of import / export to response to an economic and/or operational signal coming from any of the interconnected power systems.

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