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Power System Implications of Subsidy Removal, Regional Electricity Trade, and Carbon Constraints in MENA Economies

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Abstract

This study analyzes impacts on the power sector in the Middle East and North Africa region of three policies: removal of fuel subsidies, cross-border electricity trade, and reduction of carbon dioxide emissions in line with commitments under the Paris Agreement. The analysis uses a power system planning model that minimizes the total electricity supply cost over 2018–35 by satisfying specified technical, economic, environmental, and policy constraints. The study shows that the region would save between US$26.3 billion and US$27.5 billion, measured in 2018 prices, by removing subsidies of natural gas used for power generation. It would save US$83.6 billion to US$90.9 billion through cross-border electricity trade. The two policies together would yield a reduction of 10 percent in cumulative power sector carbon dioxide emissions in the region, with a net cost savings of US$111 billion. If a carbon constraining policy is considered to achieve the same level of reduction of emissions, the cost of the power system would increase by US$97 billion. The study also reveals that the benefits of subsidy removal would be higher in the presence of cross-border trade, and the benefits of cross-border trade would be higher in the absence of fuel subsidies.

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1. Introduction

Economic theory suggests that countries benefit from cross-border electricity trade for multiple reasons. It helps optimize the use of natural resources for electricity generation across the partner countries. It reduces the total costs of electricity supply, avoids additional investments in reserve capacity by pooling together and sharing the reserve margins. It allows infra-marginal trade of electricity, thereby increasing the capacity utilization of generation resources (Timilsina, 2018; Timilsina and Toman, 2016). Various regional power pools and cross-border electricity cooperation and trading are already in operation. These include the European Network of Transmission Operators for Electricity (ENTSOe), The Brazil-Uruguay-Argentina cross-border interconnected system; the interconnection of the Canadian province of Manitoba with the Mid-Western US States; the Greater Mekong Sub-regional interconnection; the Southern African Power Pool and the Central American Electrical Interconnection System (ESMAP, 2010).

The League of Arab States (LAS) and international development partners are currently working towards the establishment of a Pan-Arab Regional Energy Trade Platform (PA-RETP) to address the regulatory, institutional and market design issues to create a Pan-Arab Electricity Market (Camos et al. 2019). This regional electricity market would have approximately 246 GW of generation capacity to serve more than 80 million consumers. The Middle East and North America (MENA) region already has cross-border transmission lines to connect about 16 GW of generation capacity across the borders (World Bank, 2020). However, for several reasons including the absence of trading rules and regulations and prevailing subsidies, only about 2% of the total annual generation in the region is currently traded across borders in the region (IEA, 2019). The existing electricity trade to date is governed through bilateral contracts between individual countries and the sub-regions. The sub-regional cross-border electricity trade provisions consist of (a) the Maghreb sub-regional interconnection connecting power systems of Morocco, Algeria, and Tunisia[3]; The EIJLLPST (the Arab Republic of Egypt, Iraq, Jordan, Libya, Lebanon, the West Bank and Gaza, the Syrian Arab Republic, and Turkey) sub-regional interconnection; and the Gulf Cooperation Council (GCC) sub-regional power interconnection that connects six countries in the Arabian Peninsula – Kuwait, Saudi Arabia, Bahrain, Qatar, the United Arab Emirates (UAE) and Oman.

[3] These three countries' power systems are now connected and fully synchronized with the Pan-European high-voltage transmission network.

Although some progress has been made in enhancing regional cooperation and cross-border electricity trade in the MENA region, much more work is needed to fully realize the benefits of regional electricity trade through creating a regional electricity market or regional power pool. Studies analyzing the impacts of enhanced regional electricity cooperation for the MENA region are limited. The few available studies include ESMAP (2010), El-Katiri, (2011) and CESI (2014). ESMAP (2010b) focusses on Mashreq economies -- Egypt, Iraq, Jordan, the Syrian Arab Republic, Lebanon and the West Bank & Gaza. This study does not study regional trade in the rest of the MENA countries. El-Katiri (2011) does not analyze the impacts of enhanced cross-border electricity trading; it only discusses the current status and historical perspectives the regional trade. Moreover, the discussion is limited to the context of Gulf Cooperation Council (GCC) countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates), it does not cover the rest of the MENA countries.

CESI (2014) uses a power system expansion technique to analyze enhancing of cross-border electricity trading in the MENA region for 2015-2030 under multiple scenarios. The study has, however, several limitations. For example, it does not account for benefits of exploiting renewable energy resources in different parts of the region, it offers only limited information on reserve sharing and it has limited representation of the transmission networks. Moreover, the change in technologies and fuel prices and the rapid drops in costs, particularly of renewable energy technologies, warrant a fresh study to estimate the benefits of regional electricity trade in MENA under alternative scenarios.

Outside the MENA region, Timilsina and Toman (2016) estimate the benefits of a hypothetical regional power pool in the South Asia region. Timilsina and Toman (2018) further extend the study to assess the complementarity between regional trade and carbon pricing. Timilsina (2018) further explains how regional electricity trade in South Asia would help exploit the hydropower resources which have been mostly unexploited in Nepal and Afghanistan.

The main contribution of this paper is to analyze the interactions between three policies – subsidy removal, cross-border electricity trade, and carbon emission constraining in the power sector. While there are some studies dealing with fuel subsidies and GHG mitigation in the power sector, our study is the first one to investigate the interactions between these three policies covering the entire MENA region with 18 economies. The study uses a long-term electricity planning model that optimizes the regional electricity generation system meeting technical, resource, and policy constraints.

We find that the power sector benefits of a region-wide subsidy removal policy, measured in terms of cost savings from reduced power system expansion to meet projected demand, would be higher in the presence of region-wide cross-border electricity trade than that in its absence. The region-wide power sector benefits of cross-border electricity trade will be higher if such trade occurs in the absence of fuel subsidies than its presence. The subsidy removal and cross-border trade jointly lower by 10% the cumulative power sector CO_2 emissions during the 2018-2035 period, relative to a baseline, at a present value of net cost savings of US$111 billion (discounted using 6% rate) in the power sector. If a region-wide carbon pricing instrument were used in the absence of cross-border trading to achieve the same level of region-wide emission reduction, it would increase power sector expansion costs by US$97 billion.

The paper is organized as follows. Section 2 briefly describes the situation of cross-border electricity trade in the region, followed by key features of the analytical model developed in Section 3. Section 4 presents the main data and assumptions, followed by the development of policy scenarios for simulation in Section 5. Section 6 discusses the main results, and Section 7 draws the key conclusions.

2. Existing Regional Electricity Integration in the MENA Region

The regional electricity integration started in MENA long ago. The electricity trade in the Maghreb countries started in the 1950s with the cross-border transmission interconnection between Morocco, Algeria, and Tunisia. These countries were connected to the European Network for Transmission System Operators – Electricity (ENTSO-E) in 1997 via the 2x400 kV AC interconnection between Spain and Morocco. Their power systems are now fully synchronized with the European transmission network (World Bank, 2013). In 2010, the Maghreb nations signed the Algiers Declaration where they agreed to harmonize the legal and regulatory frameworks for the creation of a viable market for electricity.

The electricity transmission interconnection started between the six member states of the Gulf Cooperation Council (GCC) -- Kuwait, Saudi Arabia, Bahrain, Qatar, UAE and Oman – after the establishment of the GCC Interconnection Authority (GCCIA) in 2001. These countries signed two agreements, the General Agreement (GA) and the Power Exchange and Trade Agreement (PETA) in 2009. The GA established the principles of electricity cooperation including the rights of interconnection, connection fees, interconnection performance defaults, termination of membership and, more broadly, the interconnection's governing law. The PETA established the legal terms for commercial trade, such as the cost and contribution structures, emergency support mechanism, and other responsibilities (El-Katiri, 2011). Under the GCCIA, cross-border interconnections went through three phases. In the first phase, completed in 2009, the GCCIA formed the GCC north grid by connecting the power grids of the northern states of Kuwait, Saudi Arabia, Bahrain, and Qatar. In the second phase, it established the GCC southern grid by connecting UAE and Oman. It also formed the Emirates National Grid (ENG) by integrating the isolated networks of the various emirates and created an integrated northern grid in Oman. In the third phase, the north and south GCC grids were interconnected (World Bank, 2013). At present, the GCC electricity trade consists of (a) scheduled exchanges or the prearranged bilateral trades and (b) unscheduled exchanges or the contingency trade of electricity as needed basis, particularly during the emergency shortages (World Bank, 2013). Between 2011 and 2016, the GCC electricity trading led to more than US$2.2 billion in savings through avoidance of capital and operating cost (US$1.85 billion), reducing operational reserves and avoiding programmed outages due to emergency support (GCCIA, 2017).

The other sub-regional electricity interconnection is in the Mashreq region established by Egypt, Iraq, Jordan, the Syrian Arab Republic, and Turkey in 1988. Later, Lebanon, Libya, and the West Bank and Gaza joined the group. It is now known as EIJLLPST (Egypt, Iraq, Jordan, Libya, Lebanon, the West Bank and Gaza, the Syrian Arab Republic, and Turkey) sub-regional interconnection. The original five countries signed a general trading agreement in 1992. The general trading agreement was amended in 1996 to create a comprehensive agreement that outlines the terms and conditions for use of the interconnection, which included: reserve sharing during emergencies; capacity transactions; interchange of surplus power and energy; regulation of energy flows to maintain schedules; regulation of reactive power flows; transmission services; operating reserves; the coordination of maintenance schedules; and coordination of planning to increase reliability and maximize the value of the interconnection.

Despite the existing interconnections in the MENA region, the actual cross-border trade is limited due to tight generation supply in some countries, lack of a harmonization of connected electricity grids and other regulatory frameworks, and less developed market as the trade is limited between single government-owned entities. Moreover, the interconnected systems are often not synchronized, therefore, part of a national grid system must be isolated from the main grid to accept imports from another country (World Bank, 2013).

3. Analytical Approach

The power system planning model developed for this study is an inter-temporal or dynamic optimization model. It determines a sequence of investment decisions to build new power generation capacities while optimizing the least-cost option to meet the projected load satisfying various constraints. The constraints include the resource, technological, environmental, policy, and any other constraints specified by the modelers. The long-term investment planning and the short-term economic dispatching are part of a single joint optimization process as opposed to two separate stages. There are several simplifying features of the model. These include:

- Non-strategic participation – all countries agree to participate in a regional cost-minimizing plan; or equivalently, individual power plant owners submit their true costs as bids, and individual purchasers behave competitively in revealing their demands.
- The electricity demand projections and load forecasts in each country or grid are exogenous and perfectly price-inelastic.
- Cross-border transmission interconnections are taken as exogenous, since the region already has a large unutilized cross-border interconnection capacity.[4]

The objective function of the model is to minimize the sum of discounted values of different cost components. They include capital (investments) and fixed O&M costs, fuel costs, variable O&M costs, and costs of reliability (costs of energy not served, and costs of the reserve not meeting) in all zones (or grids) and for the entire planning horizon (all years considered).[5] The

[4] One could jointly optimize the generation and cross-border transmission systems like in Timilsina and Toman (2016). Doing so, however does not help due to the large excess or unutilized cross-border transmission capacity that is already in place or committed. It would simply complicate solving the model due to the large number of countries (18) included.

[5] Detailed description of the model, including mathematical equations, is available in World Bank (2020).

cost minimization problem is subject to the following constraints for every time interval throughout the planning horizon:

- Total energy demand is equal to the sum of generation and non-served energy.
- Available capacity equals existing capacity plus new capacity minus retired capacity.
- Power generation does not exceed the maximum and minimum output limits of a unit.
- Power generation by individual units is constrained by their ramping rates or limits.
- Reserves are committed every hour to compensate for forecasting errors.
- Renewable generation is constrained by their resource profile (i.e., the hourly rate of availability).
- Cross-border power flows are constrained by transmission network topology and transmission line thermal limits.

We use the exogenous forecasts for the peak load and most recent (2018) data for hourly load profiles. If the electricity supply is lower than the demand at a given time slot, it is referred to cost of energy not served or value of the lost load. This situation arises when supply is consistently lower than demand, thereby creating a situation of chronic outages (or load shedding) or due to scheduled or unscheduled outages. There is no universally acceptable value of lost load. Typical values used in developed economies range between $4,000 and $40,000/MWh while in developing countries it ranges between $1,000 and $10,000/MWh. In practice, it is determined through contracts with special customer groups that are willing to reduce their demand during peak hours, or with grid elements that can supply electricity. Grid elements of this category are emergency generators located in critical infrastructures and public facilities such as hospitals and government buildings, etc., to supply back-up power in case of blackouts. Typically, back-up generators are fueled with expensive fuel, diesel, and the value of the variable cost of diesel generators (~$500/MWh) is often used as the value of lost load or cost of non-energy services.

To enhance the reliability of a power system, a provision of the operational reserve is the norm. An operational reserve has two parts: (a) spinning reserves and (b) non-spinning reserves. The first refers to generators running at no load and ready to serve additional demand when needed. The second is generating units that can be started quickly (e.g., gas turbine, hydro, diesel engine) when there occurs an emergency demand due to the failure of some generation units in the system.

Thus, operating reserves (spinning and non-spinning reserves) provide adequate capability above the system demand (i.e., on top of the peak load). Thumb-rule for reserve margin is 10-15% of the peak load. While a well-interconnected system requires a lower reserve margin, an isolated grid requires a higher reserve margin.

Another critical factor of sizing a generator is its minimum load requirement. It is the parameters either specified by the manufacturer or calculated as the minimum load required for a generating unit to produce energy economically. In a power system model, it is approximated through a simple dispatch model for representative hours of the year. This constraint forces that all generating units should serve at least their minimum loading levels for specific days in the year.

Renewable generation differs from conventional units because it is intermittent; their power outputs are beyond the control of producers. Based on the forecasts of resource profile (e.g., weather forecast), the electricity generation profiles are approximated for each renewable energy technology in terms of the hourly capacity factor for a plant type (e.g., solar, wind).

The model also accounts for transmission network constraints, which refer to the capacity limits of transmission lines. The flow of electric power over a transmission line cannot exceed the designed specification limit. The model, therefore, should consider increasing transmission capacities along with generation capacities. However, to incorporate the expansion of future transmission systems into the generation expansion planning exercise requires a complex load flow analysis, including in all 18 economies considered for this study. It is beyond the scope of this study. Therefore, the model considers the transmission lines within the national boundaries, and cross-border interconnection exogenous. However, utilization of the existing transmission systems within the specified engineering design criteria is a variable in the model.

Another important feature of the model is representing storage hydropower plants. Considering the limited availability of hydro resources in MENA countries, the main hydropower plant is the pumped storage type. The existing pumped hydro storage units are aggregated at the zonal levels and represented as one unit with characteristics reflecting the ones provided by all units in the zone. Note that a pumped storage hydro is modeled differently from the conventional hydropower technology. Pumped storage hydro uses electricity from the system to pump water in a time block when electricity demand and price are low (off-peak hours). On the other hand, it generates electricity only when demand and prices are high (peak load hours).

Since the power sector is one of the primary sources of GHG emissions in MENA countries, the model estimates the GHG emissions from fuel combustion in power plants. The model can fix GHG emissions at the level specified by policy makers and calculate the shadow price of carbon mitigation. Instead of capping GHG emissions from the power sector, emission price or carbon tax can be introduced as an alternative approach to reduce power sector GHG emissions.

The model produces the following outputs:

- The marginal cost of electricity for each time block considered. It is also the electricity price with a competitive market assumption. The difference in the marginal costs of electricity is the main driver of cross-border electricity trade. A country with higher marginal costs of electricity production tends to import electricity from the one with lower marginal costs of electricity production.
- Optimal generation capacity additions, and optimal mix of electricity generation in each country for both domestic consumption and exports; including the level of exploitation of renewable energy resources for electricity generation.
- Cost savings due to the regional electricity trading.
- Volume and value of regional electricity trade.
- Amounts of GHG mitigation from the power sector.

4. Input Data and Assumptions

The main input data used in the model are: projections of peak load (load forecasts) and energy demand profiles; existing and planned generation capacities and cross-border transmission interconnections; costs (capital costs, fixed and variable O&M costs); projections of fuel prices, profiles of generation resources, particularly, of renewable energy resources (e.g., resource availability profiles measured in terms of capacity factors for each time block in each jurisdiction). Electricity generation technologies considered in the study are: open cycle gas turbine (GT), combined cycle gas turbine (CC), oil or gas steam turbine (ST), diesel generator (DG), hydro (hydro), nuclear (nuclear), coal-fueled steam turbine (coal), wind farm (wind), solar photovoltaic (PV) and concentrated solar power (CSP).

4.1. Existing and Planned Generation Capacity

Table 1 presents electricity generation capacities installed by 2018 in each economy by type of generation technology. As of 2018, the MENA region has almost 300 GW of electricity generation capacity, of which two-thirds is natural gas-based generation (gas turbine and combined cycle). The higher share of natural gas-based generation capacity reflects the fact that natural gas is locally available and gas-based generation is the cheapest source to produce electricity.

Table 1. Installed Capacity in MENA Countries as of 2018 (MW)

Economy	GT	CC	ST	DG	Hydro	Coal	Wind	PV	CSP	Total
Algeria	6,907	10,368	2,435	-	276	-	10	432	150	**20,579**
Bahrain	3,096	700	125	-	-	-	1	10	-	**3,932**
Egypt, Arab Rep.	12,647	7,845	14,799	-	2,832	-	747	50	20	**38,939**
Iraq	4,952	15,079	5,995	1,769	2,524	-	-	-	-	**30,320**
Jordan	2,837	188	242	810	-	-	287	460	-	**4,824**
Kuwait	6,496	2,925	9,354	-	-	-	10	10	50	**18,845**
Lebanon	930	140	1,694	-	253	-	-	-	-	**3,017**
Libya	3,995	4,638	1,190	-	-	-	28	-	-	**9,851**
Morocco	834	1,230	600	292	1,770	2,895	1,018	-	180	**8,819**
Oman	7,099	2,352	-	149	-	-	-	-	-	**9,600**
West Bank and Gaza	1,140	-	-	15	-	-	-	-	-	**1,155**
Qatar	7,470	4,408	-	-	-	-	-	-	-	**11,878**
Saudi Arabia	21,436	31,841	31,226	270	-	-	-	-	-	**84,773**
Sudan	458	220	906	535	2,250	110	-	-	-	**4,478**
Syrian Arab Republic	2,800	967	3,324	-	1,571	-	-	-	-	**8,662**
Tunisia	2,559	2,218	1,080	-	62	-	208	10	-	**6,138**
United Arab Emirates	21,644	6,944	2,460	31	-	-	-	373	125	**31,577**
Yemen, Rep.	-	407	495	590	-	-	-	-	-	**1,492**
Total	**107,300**	**92,470**	**75,925**	**4,461**	**11,539**	**3,005**	**2,309**	**1,345**	**525**	**298,878**

Note: CC = Combined Cycle; GT = Gas Turbine; ST = Steam Turbine; DG = Diesel Generator; Hydro = Hydroelectric; PV = Solar Photovoltaic; CSP = Concentrated Solar Power; UAE = United Arab Emirates

Source: World Bank (2020).

Electricity generation capacity additions that are either planned or are under construction between 2018 and 2035 are presented in Table 2. Of the total planned capacity additions, more than half will be natural gas based. Renewable sources of electricity (solar, wind and hydro) will share more than 10% of the total planned or committed capacity in the region. Note that the addition of new power plants also replaces retiring capacities.

Table 2. Planned/Under Construction Capacity by 2035 (MW)

Economy	GT	CC	ST	DG	Hydro	Nuclear	Coal	Wind	PV	CSP	IGCC	Total
Algeria	10,800	-	-	-	-	-	-	70	200	-	-	**11,070**
Bahrain	4,125	-	-	-	-	-	-	1	105	-	-	**4,231**
Egypt, Arab Rep.	2,430	7,940	10,550	-	32	2,400	1,950	160	179	-	-	**25,641**
Iraq	15,000	2,500	13,000	-	-	-	-	-	2,500	-	-	**33,000**
Jordan	3,000	-	900	-	-	2,000	-	600	1,100	-	-	**7,600**
Kuwait	9,350	-	-	-	-	-	-	-	60	50	-	**9,460**
Lebanon	570	-	-	-	126	-	-	-	51	-	-	**747**
Libya	250	2,910	2,800	-	-	-	-	27	15	-	-	**6,002**
Morocco	2,400	-	38	-	1,375	-	3,026	3,011	3,339	650	-	**13,839**
Oman	1,245	-	-	78	-	-	-	50	200	-	-	**1,573**
West Bank and Gaza	650	-	-	-	-	-	-	-	-	-	-	**650**
Qatar	3,549	-	-	-	-	-	-	-	200	-	-	**3,749**
Saudi Arabia	12,913	30	4,490	-	-	3,200	-	400	300	-	1,995	**23,328**
Sudan	-	-	-	37	360	-	600	-	-	-	-	**997**
Syrian Arab Republic	100	-	-	-	-	-	-	100	10	-	-	**210**
Tunisia	450	-	-	-	-	-	-	-	10	-	-	**460**
United Arab Emirates	2,299	-	1,440	-	-	2,800	-	-	-	-	-	**6,539**
Yemen, Rep.	-	-	-	-	-	-	-	-	-	-	-	**-**
Total	**69,131**	**13,380**	**33,218**	**115**	**1,893**	**10,400**	**5,576**	**4,419**	**8,269**	**700**	**1,995**	**149,096**

Note: CC = Combined Cycle; GT = Gas Turbine; ST = Steam Turbine; DG = Diesel Generator; Hydro = Hydroelectric; PV = Solar Photovoltaic; CSP = Concentrated Solar Power; IGCC = Integrated gasification combined cycle; UAE = United Arab Emirates

Source: World Bank (2020).

4.2. Peak and Energy Demand Projections

We used various sources, but mostly government sources, for the projection of peak load and energy demand. The sources include energy ministries and national electricity utilities and the Arab Forum for Environment and Development (AFED). Table 3 presents the peak load and electricity demand projections. The percentages in the table represent the annual average growth rates for given time period specified in each column. It is possible that demand growth would change depending upon the scenarios. However, forecasting the load and energy is beyond the scope of the study; they are exogenous to the electricity planning model used.

4.3. Economic and Technical Characteristics of Power Generation Technologies

The data on the economic and technical characteristics of power generation technologies are presented in Tables 4a to 4e. Economic data include costs (capital costs, O&M costs, fuel costs/prices) and fuel prices (subsidized/local and unsubsidized/international). Technical data include heat rates, natural gas availability constraints, and availability factors for renewable energy technologies.

Table 1. Peak load and energy demand forecasts (Annual Average, %)

Economy	Peak load			Energy demand		
	2020-25	2025-30	2030-35	2020-25	2025-30	2030-35
Algeria	4.0%	3.8%	4.0%	4.2%	4.0%	4.0%
Bahrain	3.1%	3.4%	3.9%	3.9%	3.7%	3.9%
Egypt, Arab Rep.	5.7%	5.4%	5.5%	6.2%	5.5%	5.5%
Iraq	1.2%	0.6%	3.9%	4.3%	3.8%	3.9%
Jordan	5.0%	4.8%	5.9%	5.3%	5.1%	5.9%
Kuwait	4.9%	2.1%	2.6%	5.4%	2.6%	2.6%
Lebanon	2.8%	2.8%	2.7%	3.2%	2.7%	2.7%
Libya	2.9%	2.5%	2.7%	3.3%	2.8%	2.7%
Morocco	5.0%	4.5%	4.8%	5.6%	4.8%	4.8%
Oman	5.2%	5.0%	5.0%	5.9%	5.4%	5.0%
West Bank and Gaza	5.1%	4.4%	4.4%	-2.2%	4.4%	4.4%
Qatar	2.6%	1.8%	1.8%	2.6%	1.8%	1.8%
Saudi Arabia	3.9%	2.1%	2.8%	4.0%	2.2%	2.8%
Sudan	12.8%	13.0%	13.1%	12.9%	13.4%	16.1%
Syrian Arab Republic	4.0%	3.7%	3.8%	4.1%	3.8%	3.9%
Tunisia	4.8%	3.8%	4.6%	5.5%	4.6%	4.6%
United Arab Emirates	6.0%	5.0%	3.7%	4.2%	3.7%	3.7%
Yemen, Rep.	5.0%	4.8%	5.9%	5.3%	5.0%	6.1%
Total	4.2%	3.5%	4.4%	4.7%	4.0%	4.5%

Source: World Bank (2020)

The capital cost, also called overnight construction cost, includes the costs of site preparation, construction, and interest during construction of power plants. While costs of solar technologies are rapidly decreasing, we considered current costs for all technologies as it is difficult to predict the capital costs of any technology. We considered both local (or subsidized) and unsubsidized (international) prices for natural gas. For other fuels, we used international prices or opportunity costs of fuels. Consideration of local and international prices for natural gas is important because two-thirds of existing power generation capacity and 55% of planned power generation capacities are natural gas based. Fuel prices are provided in Tables 4b and 4c. Table 4c provides local natural gas prices. International prices of natural gas are based on EU hubs prices, which range from \$5.0 to \$5.5/MMBTU in 2020, from \$6 to \$6.5/MMBTU in 2025 and from \$7.0 to \$7.5/MMBTU after 2025.

Since natural gas is the cheapest option in most economies, the model ends up with a corner solution implying natural gas-based generation would meet the entire electricity demand in these economies. To avoid the corner solution, we applied a constraint on the volume of natural gas to be used for power generation in each economy. The constraints are from World Bank (2020).

Renewable technologies have relatively lower capacity utilization factors because of resources (wind and solar) availability characteristics. The availability of renewable energy varies across seasons (e.g., hydro) and hourly (e.g., solar and wind). The annual average capacity factors of renewable energy technologies are provided in Table 4e. From the power system reliability perspective, we assumed that the total capacity of wind and solar PV does not exceed 40% of peak demand in a year.

Table 4. Economic and technical characteristics of power generation technologies

2a. Costs and heat rate data

Technology	Fuel	Heat Rate (MMBtu/ MWh)	Capital Cost (Million US\$/MW)	Fixed O&M cost (\$/MW-yr)	Variable O&M Cost (\$/MWh)
Gas turbine	Oil	9.75	0.81	8,100	4.05
	Natural gas	9.75	0.81	8,505	4.46
Combined cycle	Natural gas	6.0	1.22	8,370	2.24
Steam turbine	Coal	8.74	2.9	32,100	4.61
	Oil	9.45	2.5	10,530	2.37
	Natural gas	9.45	2.5	10,530	2.37
Diesel plant	Diesel	9.85	0.7	10,000	10
ISCC	Natural gas	7.45	3.77	31,180	4.42
Hydro	Water	-	2.00	14,130	-
Wind	Wind	-	1.49	31,000	-
Solar PV	Sun	-	0.97	10,000	-
Solar CSP	Sun	-	4.4	40,000	4
Nuclear	Uranium	10.48	5.5	96,200	2.21

Source: KFUPM, 2011, World Bank (2009); IEA (2014)

4b. Non-subsidized fuel prices (US$/MMBTU)

Fuel	2018	2020	2025	2030	2035
Coal	4.00	4.30	4.80	5.30	5.30
Diesel	10.00	15.20	19.10	19.10	19.10
Heavy crude oil (HCR)	7.80	11.80	14.90	14.90	14.90
Heavy fuel oil (HFO)	7.80	11.80	14.90	14.90	14.90
Light Crude Oil (LCR)	8.60	13.00	16.40	16.40	16.40
Arabian super light crude (SLCR)	11.80	15.80	18.90	18.90	18.90
Liquefied natural gas (LNG)	6.31	8.03	10.80	11.96	11.96
Refuse (REF)	4.00	4.30	4.80	5.30	5.30
Shale oil	0.40	0.50	0.60	0.70	0.70
Uranium	0.67	0.67	0.67	0.67	0.67

Source: World Bank (2016a) for coal and crude oil; USEIA (2018) for petroleum

4c. Local (subsidized) natural gas prices (US$/MMBTU)

Economy	2018	2020	2025	2030	2035
Algeria	4.50	4.50	5.50	6.50	6.50
Bahrain	5.00	5.00	6.00	7.00	7.00
Egypt, Arab Rep.	5.00	5.00	6.00	7.00	7.00
Iraq	4.00	4.00	4.50	5.00	5.00
Jordan	5.00	5.00	6.00	7.00	7.00
Kuwait	5.00	5.00	6.00	7.00	7.00
Lebanon	5.50	5.50	6.50	7.50	7.50
Libya	4.30	4.50	5.50	6.50	6.50
Morocco	5.00	5.00	6.00	7.00	7.00
Oman	3.50	3.50	4.50	5.00	5.00
West Bank and Gaza	4.50	4.50	5.50	6.50	6.50
Qatar	5.00	5.00	6.00	7.00	7.00
Saudi Arabia	5.00	5.00	6.00	7.00	7.00
Sudan	4.00	4.00	4.50	5.00	5.00
Syrian Arab Republic	5.00	5.00	6.00	7.00	7.00
Tunisia	5.00	5.00	6.00	7.00	7.00
United Arab Emirates	5.50	5.50	6.50	7.50	7.50
Yemen, Rep.	4.30	4.50	5.50	6.50	6.50

Sources: World Bank (2020)

4d. Natural gas consumption limits applied to avoid corner solution (Billion cu.m.)

Economy	2020	2025	2030	2035
Algeria	100.0	104.0	94.0	94.0
Bahrain	27.0	25.0	24.0	24.0
Egypt, Arab Rep.	75.0	76.0	70.0	70.0
Iraq	45.0	55.0	58.0	58.0

Jordan	8.0	8.0	8.0	8.0
Kuwait	10.6	18.8	22.2	22.2
Lebanon	2.0	2.0	2.0	2.0
Libya	17.0	20.0	25.0	25.0
Morocco	1.0	5.0	5.0	5.0
Oman	38.0	38.0	34.0	34.0
West Bank and Gaza	0.4	0.8	1.0	1.0
Qatar	209.0	259.0	259.0	259.0
Saudi Arabia	132.0	132.0	132.0	132.0
Sudan	0.1	0.1	0.1	0.1
Syrian Arab Republic	3.0	11.0	11.0	11.0
Tunisia	6.0	6.0	5.0	5.0
United Arab Emirates	90.0	76.0	64.0	64.0
Yemen, Rep.	0.4	2.9	6.3	6.3

Sources: World Bank (2020).

4e. Renewable energy capacity factors

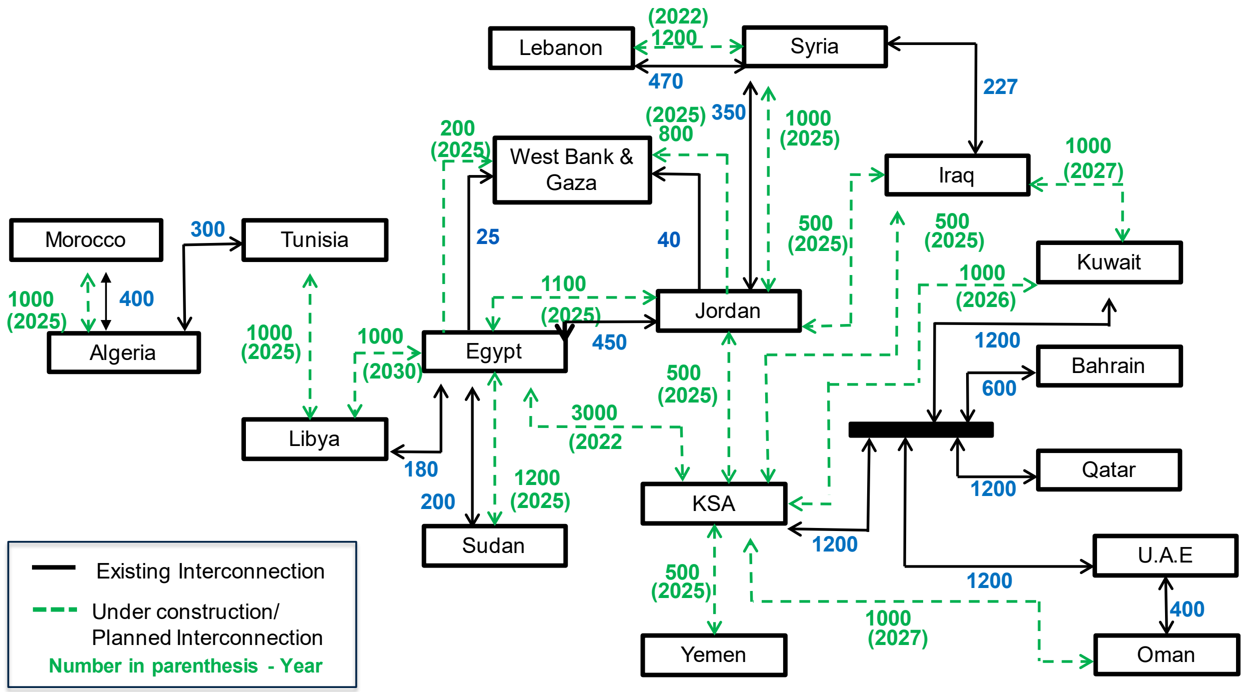
Economy	Wind	PV	CSP without storage	Hydro
Algeria	20%	23%	15%	13%
Bahrain	36%	21%	12%	-
Egypt, Arab Rep.	31%	24%	16%	55%
Iraq	17%	23%	16%	19%
Jordan	30%	26%	20%	57%
Kuwait	16%	21%	13%	-
Lebanon	16%	24%	19%	-
Libya	16%	23%	16%	49%
Morocco	21%	22%	17%	17%
Oman	31%	26%	19%	-
West Bank and Gaza	20%	22%	16%	-
Qatar	22%	22%	14%	-
Saudi Arabia	38%	26%	19%	-
Sudan	13%	24%	16%	32%
Syrian Arab Republic	13%	23%	18%	21%
Tunisia	18%	22%	16%	12%
United Arab Emirates	14%	23%	15%	-
Yemen, Rep.	18%	27%	20%	-

Sources: IHA (2017) for hydro, SolarGIS (https://solargis.com) for solar.

4.4. Cross-Border Interconnections

The existing and committed (i.e., under construction) cross-border transmission interconnections are provided in Figure 1. Among the several transmission interconnections, the 3,000MW Egypt-Saudi Arabia interconnection to be commissioned in 2022 is the largest cross-border transmission interconnection in the MENA region by 2035. The current total cross-border transmission capacity is about 11 GW; it is expected to almost double to 20 GW by 2025, and it is assumed to stay at the same level thereafter until the end of the study horizon (2035).

Figure 1. Existing and planned cross-border transmission interconnections (MW)



Note: Numbers refers to transmission capacity in MW, years when the transmission lines will be commissioned are in parenthesis

Source: World Bank (2020)

5. Scenarios Analyzed

This study considers the six scenarios or cases as defined in Table 5 for the analysis. Under Case 0, each country independently meets its projected electricity demand by expanding the required capacity within its border. Although some of the existing interconnections are in operation and cross-border trade occurs, for the simplicity of the modeling, we assumed there would be no cross-border trade in Case 0. The same is true in Cases 2 and 4. Under Case 1, the existing and planned (or under construction) cross-border interconnections capacity will be utilized to facilitate cross-border electricity trade. Case 2 and Case 3 represent cases of subsidy removal, respectively, without and with increased cross-border electricity trade. Cases 4 and 5 represent the introduction of CO_2 constraints, respectively, without and with cross-border electricity trading, and in the absence of subsidies. The carbon constraint cases (i.e., Cases 4 and 5) consider that power sector CO_2 emissions in 2025 and 2030 will be consistent with the Pan-Arab countries' Nationally Determined Contributions (INDCs) under the Paris Climate Agreement. While some economies have not published their INDCs (Libya, the Syrian Arab Republic, and West Bank and Gaza), others lacked clarity on their CO_2 reduction goals (Bahrain, Egypt, Iraq, Kuwait, Sudan and UAE), we have set NDCs, based on targets available to the rest of the MENA countries. The unconditional CO_2 reduction targets of these economies range between 1% and 13% reduction from business as usual scenario, and the conditional to international support targets range from 12.5% to 41% emissions reduction from the business as usual level by the year 2030 and would continue until 2035. Given the lack of uniformity for setting the CO_2 reduction targets by economy, this study assumes a regional limit for CO_2 emissions that increases gradually, beginning at a 10% reduction by 2025 compared to the CO_2 emissions level in 2018, and reaching 20% by 2035. Individual economies' CO_2 mitigation is endogenous in the model.

Table 5. Definition of scenarios

Case name	Condition	Definition of the case
Case 0	SUB, NO CBT	Fuels with existing subsidies and no additional electricity trade from the existing level
Case 1	SUB, CBT	Fuels with existing subsidies and electricity trade utilizing the existing and planned/under construction cross-border transmission interconnections
Case 2	No SUB, No CBT	Fuels without subsidies (international price) and no additional electricity trade from the existing level
Case 3	No SUB, CBT	Fuels without subsidies (international price) and electricity trade utilizing the existing and planned/under construction cross-border transmission interconnections
Case 4	No SUB, No CBT, CEC	CO_2 emissions limit on top of "Case 2"
Case 5	No SUB, CBT, CEC	CO_2 emissions limit on top of "Case 3"

SUB – Subsidy; CBT – Cross-border trading; CEC – Carbon emission constraining

In this study, Case 0 reflects the status quo; it will be used as the benchmark to assess the potential benefits from the subsidy removal (SR), and all three policies combined. It will also be used as the benchmark to measure the impacts of the combined implementation of subsidy removal and carbon constraint policies (SR & CEC) in the absence of cross-border trade. Case 1 will be used as the benchmark to estimate the benefits of cross-border electricity trade (CBT) in the absence of subsidy removal. It will also be used as the benchmark to estimate the impacts of subsidy removal and carbon constraint policies together in the presence of cross-border trade. Case 2 will be used as the benchmark to measure the impacts of cross-border trade and the impacts of carbon constraints in the absence of subsidies. While Case 3 will serve as the benchmark to measure the impacts of carbon constraints in the presence of cross-border electricity trade, Case 4 will do the same for measuring the impacts of cross-border in the presence of carbon constraints. The types of impacts assessed and the simulations used to measure these impacts are provided in Table 6.

Table 6. Matrix to measure the impacts

Impacts Name		Condition	Formula
Subsidy removal (SR) impacts		No CBT, no CEC	Case 2 - Case 0
		CBT, no CEC	Case 3 - Case 1
Cross-border trade (CBT) impacts		SUB, no CEC	Case 1 - Case 0
		No SUB, no CEC	Case 3 - Case 2
		No SUB, CEC	Case 5 - Case 4
Carbon emission constraint (CEC) impacts		No SUB, no CBT	Case 4 - Case 2
		No SUB, CBT	Case 5 - Case 3
Combined impacts	SR & CBT	No CEC	Case 3 - Case 0
	SR & CEC	No CBT	Case 4 - Case 0
		CBT	Case 5 - Case 1
	CBT & CEC	No SUB	Case 5 - Case 2
	ALL THREE		Case 5 - Case 0

SUB – Subsidy; CBT – Cross-border trading; CEC – Carbon emission constraining

6. Results and Discussion

This section offers the key results of the model simulations and their interpretations. We start with economic implications of regional electricity trade in the region and how the impacts under different situations, such as with and without fuel subsidies, the imposition of carbon constraints to meet the economies' NDCs. Economic effects also include changes in electricity prices and investment requirements for capacity expansion. This would be followed by physical impacts such as the expansion of electricity generation capacities, production, and trading of electricity and associated CO_2 emissions from the power sector.

6.1. Impacts on Electricity Supply Costs

Electricity supply cost here refers to the total costs of adding new capacities and operating both existing and new capacities to meet the projected load during the planning horizon (2018-2035). It includes capital or investment costs, fixed and variable operation and maintenance costs, fuel costs, and costs associated with the unmet demand and the reserve capacity. Under the cases (Case 0 and Case 1) where local or subsidized natural gas price is used, the cost of the subsidy is accounted for. The subsidy cost refers to the difference between the international and the local prices of gas multiplied by the volume of natural gas consumed for power generation.

Total electricity supply costs (discounted with a rate of 6%) for the entire region during the 2018-2035 period are presented in Figure 2. In the absence of cross-border trade and in the presence of subsidy, the total costs of electricity supply would be US$1,386 billion (Case 0). It drops to US$1,366 billion if the cost of fuel subsidy is excluded. The lowest total costs of electricity supply during the study horizon is observed in Case 3 (US$1,275 billion) when the natural gas subsidy is removed, and cross-border trade is allowed. The changes in total costs due to various effects (e.g., subsidy removal effect, cross-border trade effect, and carbon constraint effect) are provided in Table 7.

The cross-border electricity trade substantially reduces the total electricity supply costs in the region. The percentage reduction of total supply costs due to the cross-border trade would be 6% (US$83.6 billion) when the trade occurs before the removal of natural gas subsidies. The reduction will be 6.7% (US$90.7 billion) if the trade occurs after the removal of the natural gas subsidy. The highest cost savings from the cross-border trade occur when MENA economies introduce carbon constraints to meet their NDC targets. The cross-border trade saves the costs imposed by the carbon constraints by 9.2% or US$135 billion during the 2018-2035 period. Note that the carbon constraints would cause the total system costs to increase by more than 7% (US$97 billion) as compared to a situation in the absence of such constraints if there were no cross-border trade provisions. It increases at a lower rate, 4.1% (US$57 billion), in the presence of cross-border trade. Please see the last row of Table 7 that presents changes in total system cost under various impacts.

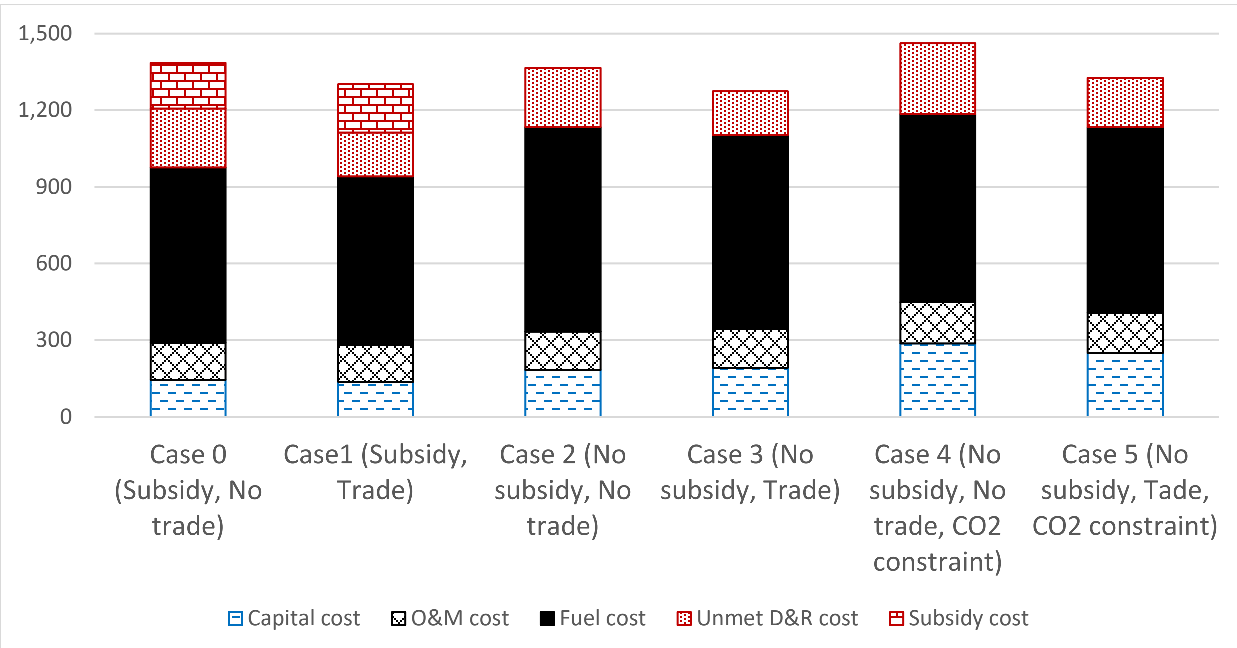
The subsidy removal reduces the system cost by 1.5% (US$20.3 billion) and 2.1% (US$27.5 billion) without and with the cross-border trade, respectively. The combined benefits of subsidy removal and cross-border trade would be US$111.13 billion in terms of cost savings (i.e., 8% reduction of total system costs).

This result implies that regional electricity trade does not only reduce the total electricity supply costs in the region but also provides economic incentives for the implementation of other policies. This result highlights the importance of the provision of cross-border electricity trade to facilitate fuel subsidy removal. The value of subsidy removal facilitated by the cross-border trade during the 2018-2035 period amount to US$7.25 billion in 2018 price. The cross-border electricity trade provision is also helpful in reducing regional CO_2 emissions from the power sector. Note that the 7.1% increase in electricity supply costs due to the imposition of carbon constraints in the absence of cross-border trade drops by three percentage point to 4.1% if cross-border electricity trade is allowed. This cost savings amounts to US$44 billion in 2018 price.

Figure 2 also illustrates various components of the total electricity supply costs. Fuel costs represent the highest share in all cases, varying between 50% and 60%. In contrary to general perception, the share of capital costs in the total system costs is low, varying between 10% (Case 0) and 20% (Case 5). The relatively higher share of capital costs in Cases 4 and 5 than that in other cases is caused by the increased penetration of renewable energy (i.e., wind and solar) in these cases to meet the carbon constraints. The operation and maintenance cost that includes both fixed and variable components accounts for 11% of the total system costs, and it does not vary noticeably across the cases. The costs associated with unmet demand and reserve capacity are relatively high, accounting for 14% to 19%, depending on the cases considered. The natural gas subsidy cost that is present only in Cases 0 and 1, accounts for 13% (Case 0) to 15% (Case 1) of the total system costs.

Table 7 also presents percentage changes in various cost components under the different cases considered. The removal of subsidies increases the fuel costs as power plants have to pay the international price for natural gas instead of subsidized local price. It also increases capital costs because of increased capacity expansion of relatively expensive renewables and nuclear power. Total capacity would also be higher due to lower capacity factors of renewables. The increase in capital cost due to subsidy removal would be much higher in the presence of cross-border electricity trade because of the higher increase in wind and nuclear capacities.

Figure 2. Total electricity supply costs (discounted) for 2018-2035 period in the MENA region (Billion US$)



The highest reductions of total system costs that are under the cross-border trade come mainly through the reduction of unmet demand and reserve costs. The cross-border trade allows the power systems in the region to share their reserve capacities; it also provides access to electricity where demands were unmet in the absence of such trade. The costs associated with unmet reserve and demand drop by more than 25% due to the cross-border electricity trade.

The carbon constraints affect capital costs as more capacities of clean power, which are relatively expensive, are required. The capital cost increases by 57% in the absence of cross-border trade (Case 4). The cross-border trade, however, lowers this burden by providing more flexibility across the region; the increase in capital costs drops to 30%. Although the drops of fuel costs due to carbon constraints vary between 4% to 8%, it would be high in the absolute terms (US$32 billion to US$64 billion) because of the higher share of fuel costs in the total system costs.

Table 7. Change in total electricity supply costs and its components for the 2018-2035 period due to the subsidy removal, cross-border trading and carbon constraint effects (%)

Cost components	SR Impacts		CBT Impacts			CEC Impacts		SR & CBT Impacts	SR & CEC Impacts		CBT & CEC Impacts	SR, CBT & CEC Impacts
	No CBT, No CEC	CBT, No CEC	SUB, No CEC	No SUB No CEC	SUB, CEC	NO SUB NO CBT	NO SUB CBT		NO CBT	CBT		
	C2-C0	C3-C1	C1-C0	C3-C2	C5-C4	C4-C2	C5-C3	C3-C0	C4-C0	C5-C1	C5-C2	C5-C0
Capital cost	27.1%	40.3%	-5.1%	4.8%	-12.8%	56.6%	30.3%	33.1%	99.0%	82.9%	36.6%	73.5%
O&M cost	2.7%	5.6%	-1.4%	1.4%	-2.8%	7.9%	3.3%	4.2%	10.8%	9.1%	4.8%	7.7%
Fuel cost	16.8%	14.8%	-3.7%	-5.4%	-1.5%	-8.0%	-4.3%	10.5%	7.4%	9.9%	-9.4%	5.8%
Unmet D&R cost	0.4%	0.5%	-25.6%	-25.5%	-29.9%	19.8%	12.6%	-25.2%	20.2%	13.1%	-16.1%	-15.8%
Subsidy cost	-100%	-100%	5.7%	-	-	-	-	-100.0%	-100%	-100%	-	-100%
Total cost	-1.5%	-2.1%	-6.0%	-6.7%	-9.2%	7.1%	4.1%	-8.0%	5.5%	1.9%	-2.8%	-4.2%

SR – Subsidy removal, CBT – Cross-border trading, CEC – Carbon emission constraining, SUB - Subsidy

6.2 Impacts on Electricity Trade

Figure 3a presents the cumulative volume of electricity exports and imports during the 2018-2035 period for all the economies. The regional electricity will cause the MENA region to trade (imports plus exports) 2,390 TWh (Case 5) to 2,903 TWh (Case 1) during the 2018-2035 period, which accounts for 6.5% to 8% of the total regional electricity generation during the period. It is about four times higher than the current level of trade in the region, which is around 2% of the total regional generation. While Saudi Arabia, Jordan, Egypt, and Qatar are the major exporters, Saudi Arabia, Egypt, and Kuwait are the major importers.

Figure 3b presents the discounted value (2018 constant price) of gains from electricity trade[6] (or trade benefits) across the economies. As noted, the gains are calculated based on some assumptions. Electricity prices are assumed to equal marginal costs. In addition, trading partners do not behave strategically; instead, they equally share the gains from the trade.

The region-wide gains[7] from the regional electricity trade would vary between US$752 million (Case 3) and US$1,282 million (Case 5) during the study period. Please note that the value of trade does not depend only on the volume of electricity traded across the border but also the difference in marginal costs between the borders. Therefore, it is possible that the gains from the trade are higher even if the volumes of the trade are lower (see Case 5).

In the absence of CO_2 constraints (Case 1 and Case 3), Egypt, Lebanon, the Syrian Arab Republic and Kuwait would receive the highest gains from electricity trade, and Bahrain, Morocco and Iraq would receive the lowest, no matter whether the natural gas subsidy is removed or not. When the CO_2 constraint is in place, Jordan replaces Kuwait in the list of top four beneficiaries (Egypt, Lebanon, and the Syrian Arab Republic remain in the top four group). Bahrain and Iraq would still be gaining the least.

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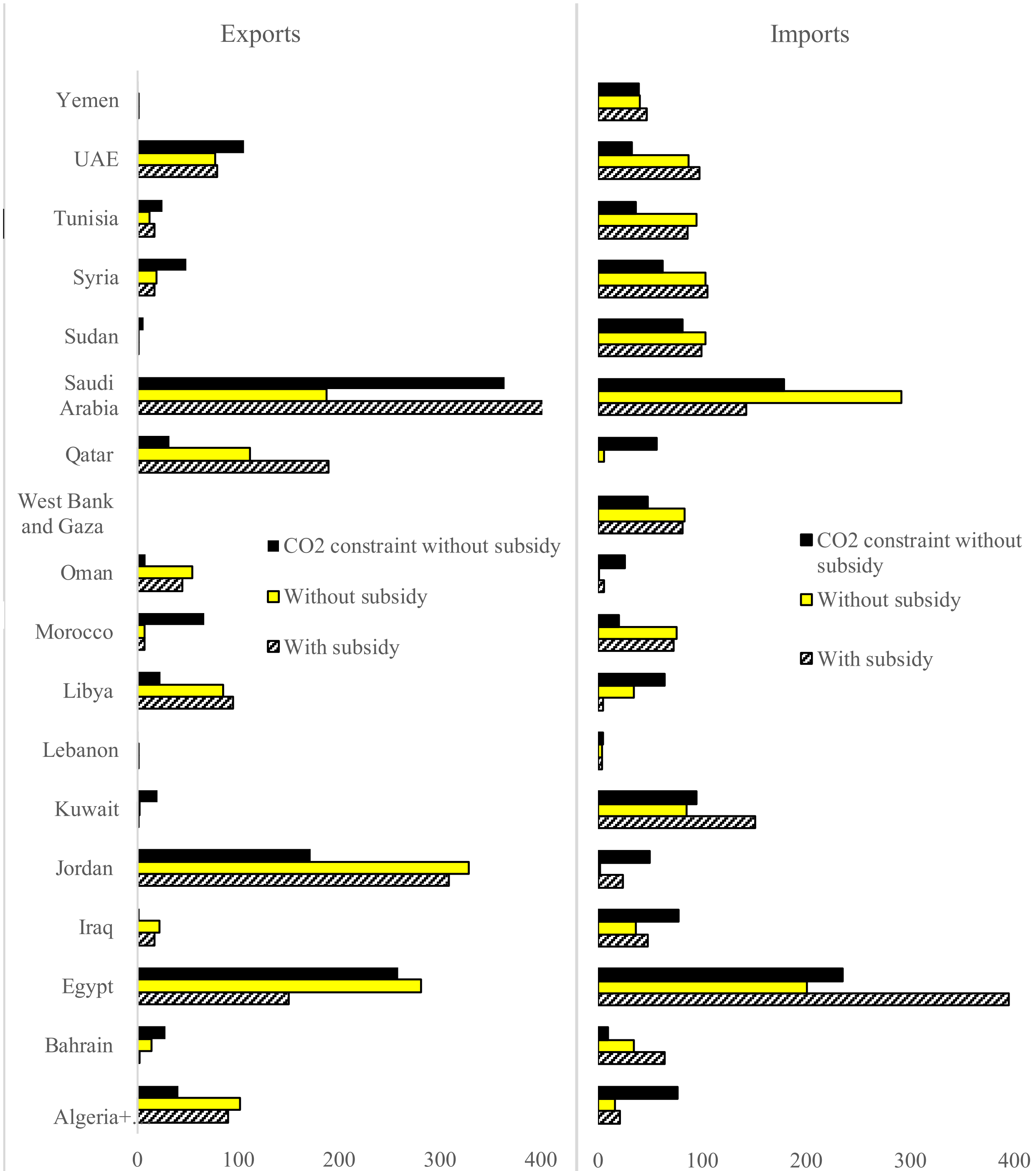
[6] Cross-border electricity trade benefits the participants through mainly two channels; (a) reduction of system expansion that includes reserve margins and (b) gains from trade. Gains occur when trade flows due to difference in marginal costs of electricity generation (electricity prices in competitive markets) and the gain is shared equally (again with the assumption of competitive, not strategic behaviors of trading partners. The cost reduction benefits have been discussed in Section 6.1; here we are discussing gains from trade.

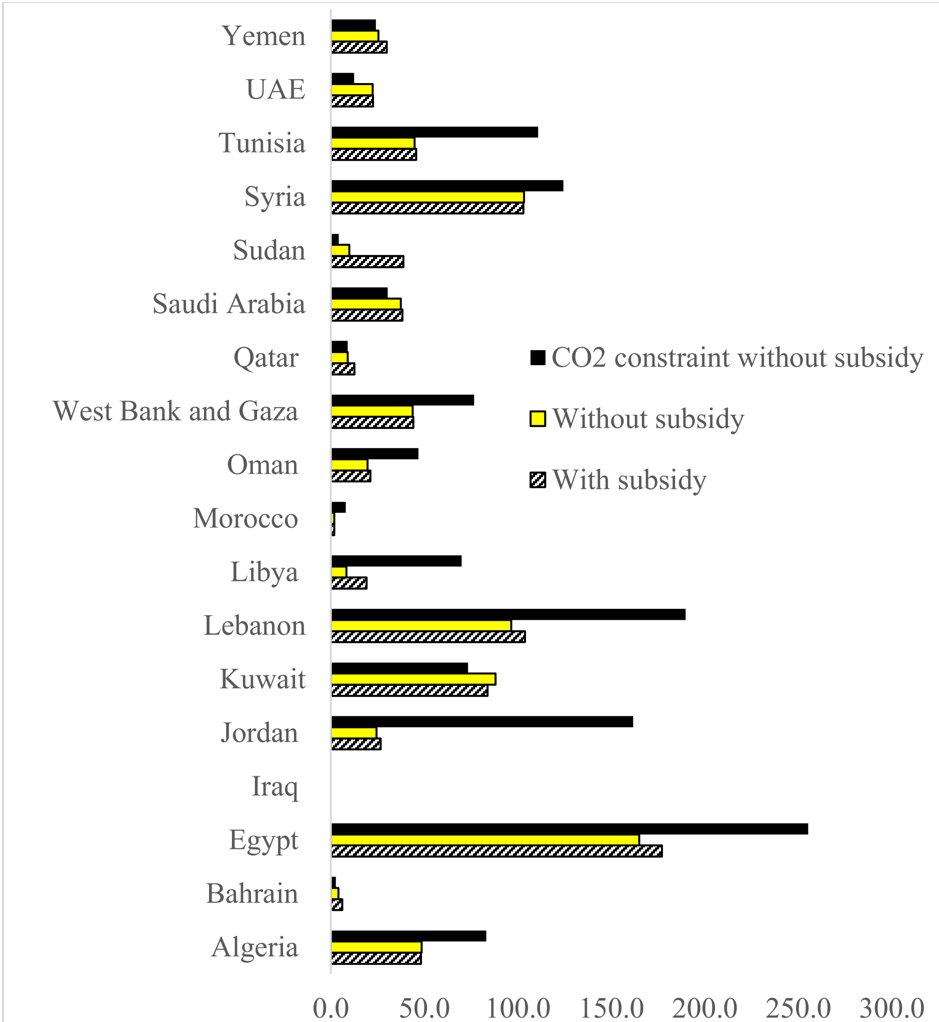
[7] There is a difference between the 'value of trade' and 'gains from trade'. The former is calculated by multiplying traded volume with the trading price. The latter is calculated by multiplying the traded volume by the difference between the trading price and the marginal costs of respective countries. It is assumed here that trading price is the average of marginal costs of the trading partners.

Figure 3. Impacts of regional electricity trade (TWh)

3a. Trade of electricity (TWh)



3b. Value of total electricity trade during the 2018-2035 period (Million US$, 2018 price)



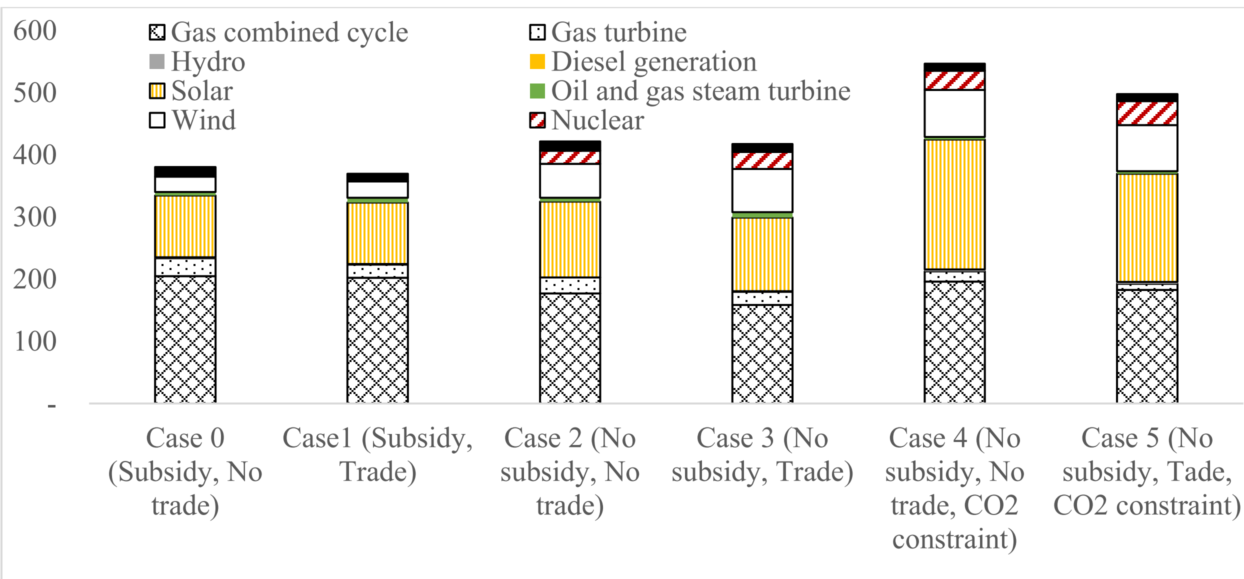
Subsidy removal reduces the gains from trade in most of the economies. The magnitude of electricity trade of a country significantly changes due to the carbon constraint. For example, the carbon constraint increases the gains from trade in UAE and Sudan by more than 500%, whereas it increases the gains by about 30% in Iraq, Libya and Yemen. Note that the carbon constraint causes to increase the imports of electricity (TWh) by more than twice in Libya, Saudi Arabia and Sudan. Similarly, electricity exports (TWh) increase by more than twice in Bahrain, Egypt, Kuwait and Yemen.

6.3 Impacts on Electricity Generation Capacity (GW) and Generation (TWh)

Impacts on capacity addition during 2018-2035 and total installed capacity by 2035 of subsidy removal, cross-border trade, and carbon constraints are presented in Figures 4a, 4b and 4c. Figure 4a presents the mix of new capacity added during the planning horizon (2018-2035); Figure 4b shows the mix of total installed capacity in 2035; and Figure 4c presents the mix of cumulative generation during the 2018-2035 period. The discussion offered below on capacity addition does not only help understand how capacity addition during the planning horizon change across the scenarios but also helps to explain the total installed capacity-mix in 2035.

Figure 4. Capacity mix and generation under various scenarios

4a. Mix of capacity added during the planning horizon (2018-2035) (GW)



4b. Mix of total installed capacity in 2035 (GW)

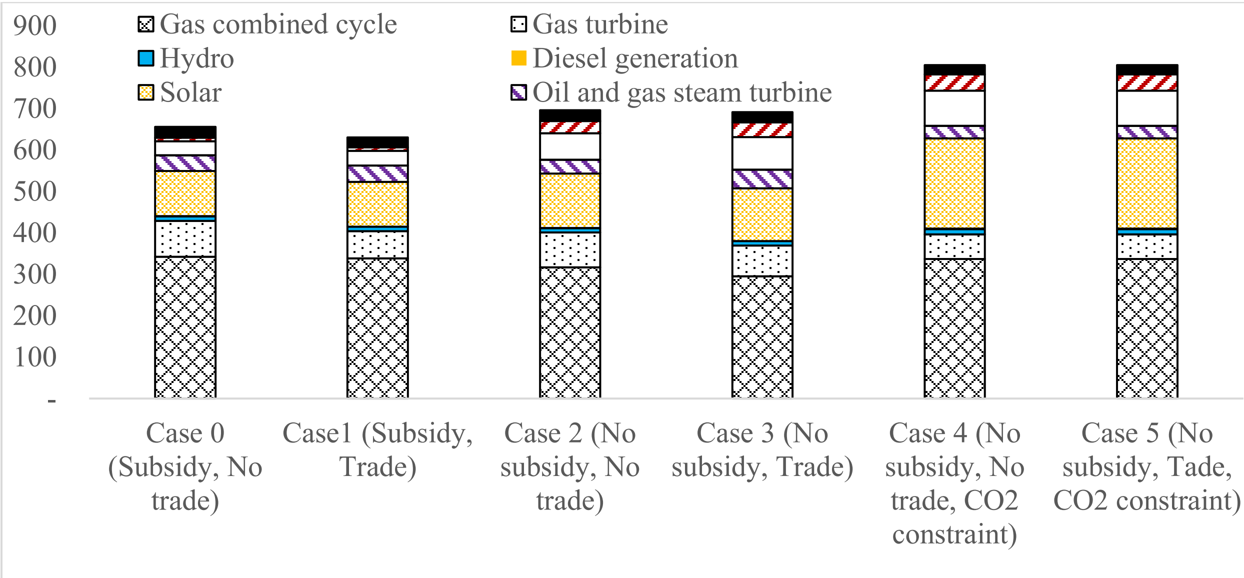
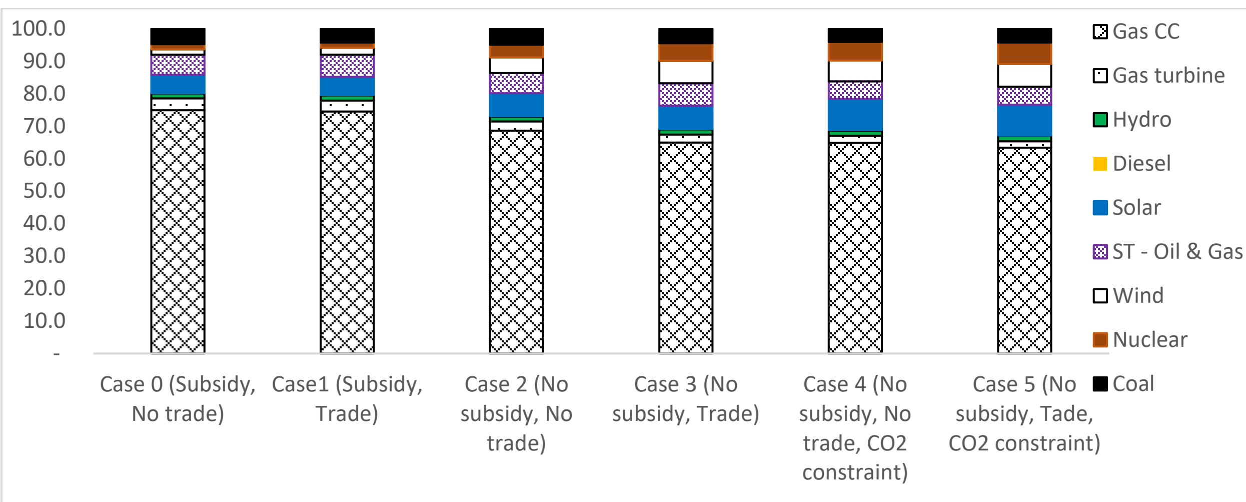


Figure 4c. Generation mix based on cumulative generation for the 2018-2035 period (%)



The type and size of electricity generation capacity addition depend on the objective of the scenario analyzed. Combined cycle power plants that generally serve the baseload amount to the highest level of addition in all scenarios, except Case 4. Its share in total capacity addition during 2018-2035, would vary from 36% in Case 5 to 54% in Case 0. The factor that causes this variation is carbon constraint. In Case 5, a much higher level of solar and wind capacities are needed to meet the specified carbon constraints. Interestingly, the expansion of solar registers second place after the gas CC except in Case 4 where the expansion of solar tops all other types of electricity generation technologies.

Renewable sources of electricity generation and, to some extent nuclear power, replace gas-based power generation, particularly the combined cycle power plants. Change in generation-mix is a good indicator to explain how the generation of electricity from various technologies respond to policies considered. Moreover, this indicator will also be useful later to explain CO_2 emissions change across the different scenarios considered.

The most notable effects of the policies considered (i.e., subsidy removal, cross-border electricity trade, and CO_2 reduction) fall on gas-CC, solar power and wind power and nuclear technologies both in terms of capacity expansion and electricity generation (see Table 8). When the subsidy is removed in the absence of regional trade, 28 GW of combined cycle and 3 GW of gas turbine plants would be replaced with solar (23 GW), wind (30 GW) and nuclear (21 GW) capacity. This is because the removal of subsidy from natural gas makes power generation from natural gas-based power plants expensive and that from renewables and nuclear relatively cheaper. Note that 74 GW of non-fossil fuel-based plants (solar, wind and nuclear) are needed to replace less than a half (31 GW) of fossil fuel-based plants because solar and wind have much lower capacity factors. It would cause a net increase of 42 GW of total electricity generation capacity due to subsidy removal in the absence of cross-border trade.

In the presence of cross-border electricity trade, the subsidy removal policy causes further expansion of wind and nuclear capacities. Thus, a subsidy removal policy would work better to promote renewable energy technologies in the presence of cross-border trade as compared to the situation when cross-border trade does not exist. It would, however, increase the total capacity addition during the 2018-2035 period further (48 GW). This is further illustrated in Figure 4c, where we can notice that electricity generation from gas-CC technology is avoided substantially under Case 2 to Case 5. Also avoided in these cases are the generations from gas and oil-based steam turbine technology but much smaller as compared to the avoidance of gas-CC technology.

Although the cross-border trade facilitates the renewable energy promotion effect of subsidy removal policy, it itself does not help much to expand the renewable energy-based electricity generation capacities. This is because cross-border trade reduces the total capacity addition in the region as the economies can now share each other's generation capacities. Cross-border electricity trade causes the total capacity addition during the 2018-2035 period in the region to drop by 10 GW in the presence of the subsidy and 4 GW in the absence of the subsidy. Since total capacity requirement declines, capacity addition also declines. Thus, the cross-border electricity trade causes a decline of solar capacity addition by 1 GW in the presence of subsidy and 4 GW in the absence of the subsidy. It is, however, clear that subsidy removal helps to reduce this decline.

Solar would be the primary contributor to meet the NDC targets in the MENA region. In the absence of cross-border trade, 87 GW of additional (on top of solar capacity added in the absence of both subsidy and cross-border trade or Case 2) solar capacity would be added. If there is cross-border trade, corresponding solar capacity addition will decrease (56 GW). Wind, nuclear and combined cycle power plants also play a great role in meeting NDC targets in the MENA region. To meet the carbon constraint in the absence of cross-border trading (Case 4), 19 GW of combined cycle, 21 GW of wind and 10 GW of nuclear would be needed on top of the corresponding capacities added in the absence of both subsidy and cross-border trade (Case 2). Under the carbon constraint (or contribution to NDC obligation) scenario, total capacity addition is significantly high (125 GW) in the absence of cross-border trade. If the cross-border trade is allowed, it drops to 80 GW because of the flexibility gained through the cross-border trading. It, however, requires additional capacities of combined cycle and nuclear plants.

The directions of changes in electricity generation under the various policies are similar to those of changes in total electricity generation capacities, the only difference is in the magnitude of change. For example, the share of solar in the total electricity generation vary from 5.7% under Case 1 (No subsidy, No Trade) to 9.6% under Case 4 (No subsidy, No Trade, Carbon constraint). On the other hand, the share of solar in total installed capacity varies from 16.6% (Case 1) to 27.1% (Case 4). The difference in magnitude of impacts between the total installed capacity and generation is caused by the lower capacity factors of renewable energy-based power generation technologies.

Table 8. Changes in new capacity addition (GW) and generation mix (percentage point) due to subsidy removal, cross-border trading and carbon constraint effects

Electricity generation technology	SR Impacts		CBT Impacts			CEC Impacts		SR & CBT Impacts	SR & CEC Impacts		CBT & CEC Impacts	SR, CBT & CEC Impacts
	No CBT, No CEC	CBT, No CEC	SUB, No CEC	No SUB No CEC	SUB, CEC	NO SUB NO CBT	NO SUB CBT		NO CBT	CBT		
	C2-C0	C3-C1	C1-C0	C3-C2	C5-C4	C4-C2	C5-C3	C3-C0	C4-C0	C5-C1	C5-C2	C5-C0
Change in new capacity addition during the 2018-2030 period (GW)												
Combine cycle	-28	-44	-2	-18	-14	19	24	-46	-9	-20	6	-22
Gas turbine	-3	0	-8	-5	-7	-9	-11	-8	-13	-11	-16	-20
Hydro	-1	0	0	1	0	3	2	0	2	2	3	2
Diesel generation	0	0	0	0	0	0	0	0	0	0	0	0
Solar	23	19	-1	-4	-35	87	56	19	109	75	52	75
Steam turbinea	0	1	2	3	0	-2	-4	3	-1	-3	-2	-2
Wind	30	44	1	15	-1	21	4	45	51	48	19	49
Nuclear	21	27	0	6	8	10	11	27	31	39	17	39
Coal	0	0	-2	-2	0	-4	-2	-2	-4	-1	-4	-4
Total	42	48	-10	-4	-49	125	80	37	166	128	76	118
Change in generation mix during the 2018-2035 period (percentage point)												
Combine cycle	-6.32	-9.57	-0.39	-3.64	-1.48	-3.75	-1.59	-9.96	-10.07	-11.16	-5.23	-11.54
Gas turbine	-0.80	-0.88	-0.26	-0.34	-0.18	-0.65	-0.49	-1.14	-1.45	-1.37	-0.83	-1.63
Hydro	0.00	0.00	0.05	0.05	0.00	0.16	0.12	0.05	0.16	0.11	0.16	0.16
Diesel generation	0.00	0.00	-0.01	-0.01	-0.03	0.03	0.02	-0.01	0.03	0.01	0.00	0.00
Solar	1.47	1.63	-0.04	0.12	-0.17	2.47	2.19	1.58	3.94	3.81	2.30	3.77
Steam turbine[a]	-0.01	0.14	0.60	0.75	0.15	-0.76	-1.37	0.74	-0.77	-1.23	-0.62	-0.63
Wind	3.22	4.59	0.55	1.92	0.62	1.50	0.20	5.14	4.72	4.79	2.11	5.33
Nuclear	2.26	3.86	0.00	1.61	0.94	1.85	1.19	3.86	4.11	5.06	2.80	5.05
Coal	0.18	0.23	-0.50	-0.45	0.15	-0.86	-0.26	-0.26	-0.67	-0.02	-0.71	-0.52

[a] running with natural gas or crude oil or heavy fuel oil

SR – Subsidy removal, CBT – Cross-border trading, CEC – Carbon emission constraining , SUB - Subsidy

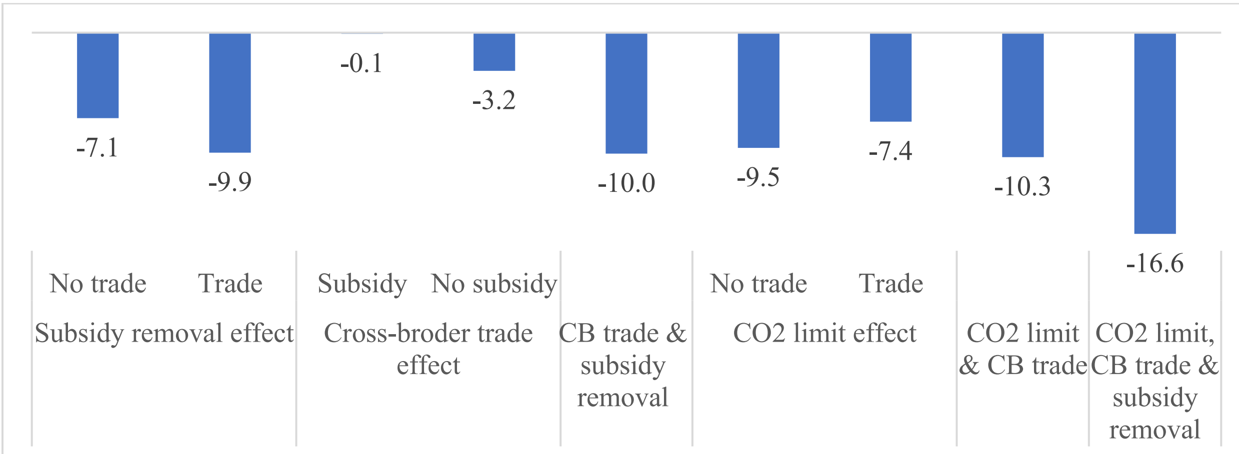
6.4 Impacts on CO_2 Emissions

Figure 5 presents CO_2 emissions from the power sector in the MENA region under various scenarios. The removal of subsidy would reduce power sector CO_2 emissions during the 2018-2035 period by 7.1% in the absence of cross-border trade. The reduction increases by 2.8 percentage points in the presence of the cross-border trade (from 7.1% to 9.9%). This implies that the cross-border trading provision facilitates the substitution of fossil fuels with renewable energy. The impacts on CO_2 emissions of the cross-border trade would be much smaller in the presence of subsidy (0.1%). However, it increases to 3.2% in the absence of the subsidy. Interesting to note is that CO_2 mitigation under subsidy removal cases would be much higher than that under the cross-border electricity trade cases.

The carbon constraints imposed corresponding to NDC targets would cause a reduction of 9.5% of power sector CO_2 emissions in the region in the absence of cross-border trade and in the absence of the subsidy. The reduction, however, decreases in the presence of the cross-border trade. This is counterintuitive. The cross-border trade seems to allow importing more electricity from fossil fuel sources than renewable sources because of former is relatively cheaper than the latter. Moreover, even if renewable electricity is cheaper, it may not be available due to its intermittent nature. A country with a cross-border electricity trade agreement has to run fossil fuel-based plants to honor its contractual agreement if renewable sources are not available. If the CO_2 constraint is imposed together with the subsidy removal and cross-border electricity trade, the total regional power sector CO_2 emissions would drop by 16.6% during the 2018-2035 period.

Table 9 provides additional insights on the CO_2 mitigation effects of subsidy removal, cross-border trade and carbon mitigation policies by digging model results at the individual country level. The CO_2 mitigation effect of subsidy removal policy is more prominent in Saudi Arabia, Qatar and UAE because these countries get affected the most when the natural gas subsidy is removed. Several countries, such as Algeria, Egypt and Yemen, experience an increase in CO_2 emissions due to subsidy removal when cross-border electricity trade is allowed. This is because electricity generation increases in these countries to meet export demand.

Figure 5. Impacts on cumulative power sector CO_2 emissions during the 2018-2035 period (%)



Cross-border electricity trading causes a large percentage reduction in many of the economies with or without the presence of natural gas subsidy. For example, the cross-border electricity trade causes more than 20% of CO_2 reduction during the 2018-2035 period in Bahrain, West Bank and Gaza, the Syrian Arab Republic, Tunisia and Yemen in the presence of subsidy. These economies import electricity if cross-border electricity trade is allowed and generate less at home, thereby reducing CO_2 emissions. However, cross-border trading increases CO_2 emissions in Algeria, Qatar, Oman, Saudi Arabia, Libya, Jordon and UAE. At the regional level, the reduction of CO_2 by the first set of economies is completely offset by the increase in CO_2 in the second set of economies.

In the absence of subsidy and cross-border trade, the carbon constraint policy causes all the economies to reduce their emissions. The percentage reduction of CO_2 emissions for the 2018-2035 period varies from 7.7% (Saudi Arabia) to 14.4% (Yemen). However, if cross-border electricity trade is allowed, carbon constraining (Case 5) would cause some economies to increase emissions from the situation in the absence of carbon constraint (Case 2). Countries such as Morocco, Saudi Arabia, the Syrian Arab Republic and Tunisia would have reduced more emissions under the cross-border electricity trade (in the absence of subsidy) without carbon constraints than that with carbon constraints.

Table 9. Change in power sector CO_2 emissions due to subsidy removal, cross-border trading and carbon constraint effects (%)

Electricity generation technology	SR Impacts		CBT Impacts			CEC Impacts		SR & CBT Impacts	SR & CEC Impacts		CBT & CEC Impacts	SR, CBT & CEC Impacts
	No CBT, No CEC	CBT, No CEC	SUB, No CEC	No SUB No CEC	SUB, CEC	NO SUB NO CBT	NO SUB CBT		NO CBT	CBT		
	C2-C0	C3-C1	C1-C0	C3-C2	C5-C4	C4-C2	C5-C3	C3-C0	C4-C0	C5-C1	C5-C2	C5-C0
Algeria	0.0	3.2	2.0	5.2	0.1	-9.5	-13.9	5.2	-9.5	-11.1	-9.4	-9.4
Bahrain	-1.6	0.0	-21.8	-20.6	-3.0	-8.9	11.3	-21.8	-10.3	11.3	-11.6	-13.0
Egypt, Arab Rep.	0.0	5.9	-8.3	-2.9	0.0	-9.8	-7.0	-2.9	-9.8	-1.5	-9.7	-9.7
Iraq	-0.2	-0.3	-0.5	-0.6	-0.1	-9.1	-8.7	-0.8	-9.3	-8.9	-9.2	-9.4
Jordan	0.8	9.2	54.8	67.8	0.0	-10.8	-46.8	69.1	-10.1	-41.9	-10.7	-10.0
Kuwait	-2.0	-0.2	-7.8	-6.1	0.1	-9.3	-3.2	-8.0	-11.1	-3.5	-9.2	-11.0
Lebanon	0.0	0.0	-1.0	-1.1	0.6	-8.8	-7.3	-1.1	-8.8	-7.4	-8.3	-8.3
Libya	-3.2	-6.4	8.1	4.6	1.1	-9.9	-12.9	1.2	-12.8	-18.5	-8.9	-11.8
Morocco	-0.1	1.8	-19.7	-18.3	-1.1	-10.2	8.6	-18.3	-10.3	10.5	-11.2	-11.3
Oman	-0.6	-5.5	5.3	0.1	0.0	-9.8	-9.9	-0.5	-10.3	-14.8	-9.8	-10.3
West Bank and Gaza	0.0	2.4	-51.8	-50.6	-24.4	-9.7	38.4	-50.6	-9.7	41.7	-31.7	-31.7
Qatar	-3.7	-11.7	21.3	11.1	0.0	-8.9	-18.0	7.0	-12.3	-27.6	-8.9	-12.3
Saudi Arabia	-25.3	-37.3	4.9	-11.9	-2.2	-7.7	2.4	-34.2	-31.1	-35.7	-9.8	-32.6
Sudan	0.0	-0.3	-7.1	-7.4	-1.3	-13.4	-7.7	-7.4	-13.4	-8.0	-14.5	-14.5
Syrian Arab Republic	0.0	1.3	-32.7	-31.8	-3.9	-11.5	24.7	-31.8	-11.5	26.3	-15.0	-15.0
Tunisia	-0.3	-3.6	-22.4	-25.0	-1.9	-10.4	17.2	-25.2	-10.7	13.0	-12.1	-12.3
United Arab Emirates	-5.6	-11.4	5.3	-1.1	0.0	-9.0	-7.9	-6.7	-14.1	-18.4	-9.0	-14.1
Yemen, Rep.	0.0	9.4	-26.3	-19.4	-7.9	-14.4	-2.2	-19.4	-14.4	7.0	-21.1	-21.1

[a] running with natural gas or crude oil or heavy fuel oil

SR – Subsidy removal, CBT – Cross-border trading, CEC – Carbon emission constraining , SUB - Subsidy

A very interesting finding is that the region could achieve more reduction of CO_2 emissions by combining subsidy removal and cross-border trade than the carbon constraints in line with their NDCs. Even if the CO_2 constraint is implemented along with the cross-border electricity trade, not much additional reduction of CO_2 emissions observed. However, if the subsidy removal is also implemented along with carbon constraint, it would substantially increase the CO_2 reduction in the region. This explains the importance of subsidy removal from the environmental perspective in the MENA region.

7. Conclusions

This study investigates impacts on the power sector in the Middle East and North Africa region of three policies: removal of fuel subsidy, cross-border electricity trade, and CO_2 reduction constraint. We develop a power system generation expansion model for assessing the impacts. An important contribution of the paper is that it captures the interactions of these policies. The study finds that with the removal of subsidy in natural gas, the primary fuel to produce electricity in the MENA region, the region would save from US$20.3 billion (in the absence of cross-border trade) to US$27.5 billion (in the presence of cross-border trade)[8] during the 2018-2035 period. Similarly, the cross-border electricity trade would save the regional electricity supply costs from US$83.6 billion (in the presence of subsidy) to US$90.7 billion (in the absence of the subsidy). If the countries in the region were to introduce carbon constraints to contribute to their GHG mitigation obligation under the Paris Agreement, they should do so in the presence of cross-border trade because it saves US$135 billion.

The study reveals interactions of subsidy removal and cross-border electricity trading to each other and their effects on CO_2 reduction policies. The regional savings of electricity supply costs from subsidy removal would be 36% higher if the subsidy removal occurs in the presence of cross-border electricity trade than when it occurs in the absence of such trade. The cost savings due to the cross-border electricity trading would be 9% higher if the trade occurs in the absence of fuel subsidies than when it occurs in the presence of fuel subsidies.

[8] Discounted using 6% rate and expressed in 2018 price.

Contrary to expectation, the study also shows that the cross-border electricity trade itself does not help much promote renewable energy expansion in the MENA region because the trade reduces the total capacity requirement through sharing of capacities and reserve margins across the countries. On the other hand, the removal of natural gas subsidy substantially promotes renewable energy as the latter becomes cost-competitive. Interestingly, the renewable energy expansion effect of subsidy removal policy would be more prominent in the presence of cross-border electricity trade as compared to the situation in the absence of such a trade. The expansion of solar and wind capacities due to natural gas subsidy removal in the presence of cross-border electricity trade would be 21% higher than that in the absence of the trade.

Subsidy removal and electricity trade affect the power sector CO_2 emissions. An interesting finding is that these two policies together reduce 10% of the power sector emissions during the 2018-2035 period with net regional cost savings of US$111 billion. On the other hand, to achieve the same level of power sector emission reduction, the carbon constraining policy would cost US$97 billion. If the CO_2 constraining policy is combined with the subsidy removal policy, they would together reduce 15.9% of power sector CO_2 emissions at the net cost of US$77 billion in the absence of cross-border trade. The cross-border trade plays the biggest role in reducing CO_2 mitigation costs. If all three policies are combined, they would reduce 16.6% of power sector CO_2 emissions at net savings of US$58 billion during the 2010-2035 period.

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