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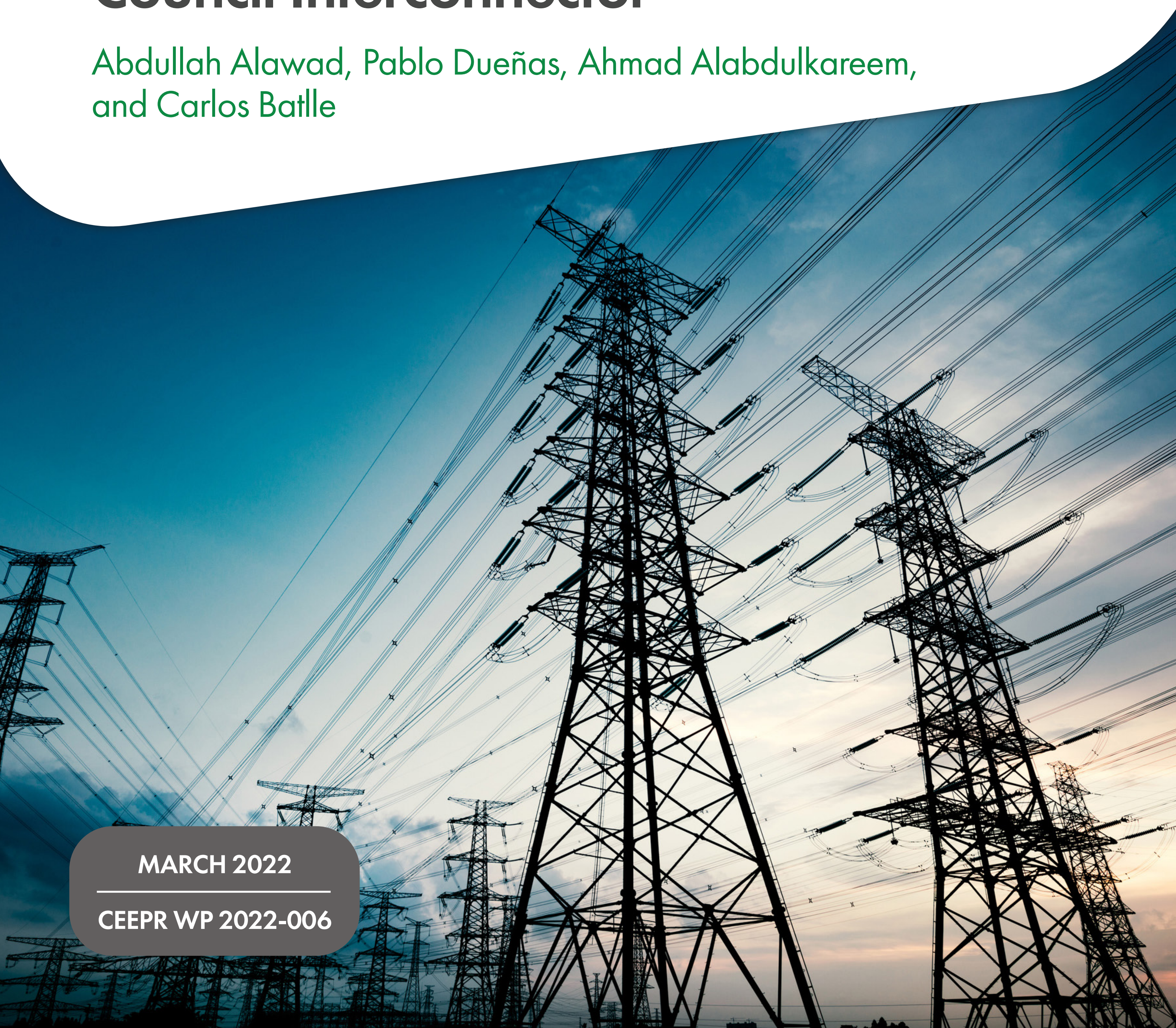

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COPING WITH NATIONAL FUEL SUBSIDIES IN REGIONAL POWER MARKETS: APPLICATION TO THE GULF COOPERATION COUNCIL INTERCONNECTOR

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Abstract

Transnational power market design and development are impacted by economic, social and political factors that must inevitably be addressed. One of the most prominent and widespread such factors are energy subsidies, i.e. measures aimed at keeping prices for electricity end users below market levels. Traditionally regional markets regulation has aimed at banning such subsidies, to properly ensure healthy competition, in order to maximize short- and long-term economic efficiency. However, as we evidence by reviewing the different regional markets implemented not just in the EU and the US but worldwide, experience increasingly shows that the trend does not lead to the removal of these subsidies, but quite the contrary. As a result, at this stage, it is worth looking for innovative regional market design solutions to take the best of the integration of different power system, while coping with the existence of this sort of national subsidization mechanisms.

In particular, this article explores how the efficiency of regional electricity markets can be optimized when coexisting with national fuel subsidies. To achieve this aim, we propose original and simple bidding conditions and market clearing methods whereby one of two prices may be attributed to each generating unit depending on whether final delivery targets domestic or export demand. The proposal, designed to favor transitioning to integrated regional markets as hopefully countries gradually eliminate subsidies, is illustrated with a full-scale case study, the Gulf Cooperation Council Interconnection, where the reluctance to comply with that limitation might be underlying governments' unwillingness to commit to regional integration.

Keywords

Regional power markets; fuel subsidies; power trading; unit commitment; economic dispatch.

1 INTRODUCTION

One key aspiration for countries the world over in recent decades has been the institution of regional markets to integrate several national/state power grids. Regional market initiatives, from embryonic to highly developed, can be found on five continents, including for instance: the US's pioneering Regional Transmission Operators (FERC, 2000), which later gave rise to the so-called ISO markets; the Central American Regional Electricity Market (Echevarría et al., 2017; EOR, 2019); the National Electricity Market (NEM) in Australia (Outhred, 2004); the European Internal Electricity Market, resulting from the integration of previously developed regional experiences, as for instance the Nordic or Iberian markets (Gouardères, 2019; Erbach, 2019); the Southern African Power Pool (Eberhard, 2019); and the market to be built around the Gulf Cooperation Council Interconnection (GCCI).

In addition to improving short-term reliability, integrating contiguous markets can lower power supply costs through coordinated operation and eventually integrated energy resource investment planning. The materialization of such benefits necessitates thoughtful market design informed by technical, economic and institutional analyses of the regional system. More specifically, market design must address not only the technical issues that condition the performance of the regional power system, but also other constraints associated with socio-political objectives, deemed to be a high priority by some member states.

Trading in power exchanges is thus limited not only by grid constraints and agents' operational and economic characteristics, but as well as by other conditioning factors that must be borne in mind when concluding supply agreements or participating in power auctions. So the design of all the mechanisms in place in organized markets for electricity, from capacity markets to day-ahead, intraday and balancing markets need therefore to allow accommodating such constraints in the most efficient way possible.

One of the most prominent and widespread such factors are energy subsidies, i.e. measures aimed at keeping prices for electricity end users below market levels. Traditionally regional markets regulation has aimed at banning such subsidies, to properly ensure healthy competition, in order to maximize short- and long-term economic efficiency. However, as we evidence later in section 2.2 by reviewing the different regional markets implemented not just in the EU and the US but worldwide, experience increasingly shows that the trend does not lead to the removal of these subsidies, but right the contrary. As a result, at this stage, it is worth looking for innovative regional market design solutions to take the best of the integration of different power system, while coping with the existence of this sort of national subsidization mechanisms.

In particular, this article focuses on one of the key pieces of regional markets design, the pricing mechanism in the day-ahead market. This design element, built upon the defined bidding formats and the specific clearing algorithm is instrumental to optimize the efficiency of the market results, see for instance the in-depth discussion developed by Richstein et al. (2020), showing how different bidding formats condition efficiency gains in the presence of uncertainty in electricity markets. In the presence of any sort of subsidization policy, designing mechanisms to optimize price calculation subject to these higher order constraints happens to be instrumental. To achieve this aim, we propose original and simple bidding conditions and market clearing methods whereby one of two prices may be attributed to each generating unit depending on whether final delivery targets domestic or export demand. The proposal, designed to favor transitioning to integrated regional markets as hopefully countries gradually eliminate subsidies, is illustrated with a full-scale case study, the Gulf Cooperation Council Interconnection, where the reluctance to comply with that limitation might be underlying governments' unwillingness to commit to regional integration.

As discussed in a later section of this article, relief for end consumers can be provided with many other less inefficient approaches than subsidizing the fuel used to generate power (Komives et al., 2005). While the present authors by no means favor keeping such subsidies in place in such a format, they do not object adamantly to the practice. Rather, they advocate for enhancing regulatory design to minimize its adverse effects on system efficiency, in the understanding that the existence of government aid of this nature in many jurisdictions hobbles regional market integration.

The algorithm proposed for a bidding and clearing scheme, tested in the case study described, aims to fell or lower this barrier to the establishment of transnational markets and pave the way for progress in that regard. As the case study shows, the proposal envisages the inclusion of generating units sited in countries where generation-side fuel subsidies are in place for domestic demand only. Under the terms of the proposal, such units would be in a position to export their output when below the auction cut-off price, while not actually needing to "export" the subsidy. Such domestic target-only subsidies are routine in a fair number of jurisdictions (see discussion in the section below). The same approach could serve as grounds for developing a simulation model with which to estimate regional prices in the presence of such constraints and determine their impact on market efficiencies under strictly cost-based dispatching.

Benefits of regional integration

Ideally, regional markets should merge into a single market to ensure environmentally sustainable power supply at the lowest possible cost compatible with satisfactory service quality. When all the features of such systems are in place, as the market operates as a single entity irrespective of political geographic divisions, it maximizes social benefit (Hobbs et al., 2005), (Lise et al., 2006), (ESMAP, 2010), (Olmos et al., 2018).

Interconnecting a number of domestic systems affords obvious short-term benefits, both technically and economically speaking, for sharing reserves stabilizes power frequency and raises the reliability of each individual system, given the support provided by neighboring grids in emergency situations. The earliest attempts at interconnection sought such enhanced reliability, as well as safer and more robust system performance at lower cost.

Regional markets, however, pursue more ambitious goals than short-term security of supply and the concomitant economic savings. Their stated purpose is to capitalize on the enormous potential of international power trading, often among countries with different energy mixes (hydraulic or other renewable sources with varying seasonality), demand patterns, investment cycles, fuel access conditioning factors and so on, not to mention the enlargement of the size of the market. That expansion favors competition (Böckers, 2013) while at the same time establishing economies of scale for some investments, clearly benefitting small countries. The ultimate objective is to eliminate political boundaries as far as reasonably possible to optimize investment, operation and risk hedging in all the component systems to reap the respective economic and environmental benefits.

2 CONDITIONING FACTORS IN REGIONAL ELECTRICITY MARKET INTEGRATION: FUEL CONSUMPTION SUBSIDIES FOR ELECTRICITY GENERATION

Energy has traditionally been deemed one of the strategic resources on which national independence hangs. Given that energy policy at times pursues conflicting goals (security of supply, competitive pricing and environmental sustainability), governments are often required to perform complex balancing acts. The cost of power generation and retail pricing may vary substantially among market members, prompting governmental reluctance to open their electric power markets to other players. That on occasion may be attributable to the fear that the interests of domestic consumers and/or suppliers might be jeopardized by more competitive foreign service providers. Institutional and regulatory obstacles to regional markets must consequently not be underestimated (de Jong, 2004) (Singh, 2018).

2.1 Generation-side fuel subsidies: worldwide trends

Worldwide estimates on subsidies to lower the cost of fossil fuels cost to below market prices are published yearly by the International Energy Agency (IEA). The origin of such aid may be funding provided directly by the government or, as discussed in a later section, through a state-owned power company. Fossil-fuel subsidies generally take two forms: i) production subsidies are tax breaks or direct payments that reduce the cost of producing coal, oil or gas; ii) consumption subsidies, meanwhile, cut fuel prices for the end user, such as by fixing the price at the petrol pump so that it is less than the market rate. In some countries, such as the Middle East, the subsidies are sometimes regarded as helping citizens to benefit from a country's endowment of natural resources (Timperley, 2021).

The main justification primarily given for such subsidies, especially in developing countries, is the need to mitigate energy poverty. But that is not their sole objective, however, as they may also constitute a tool for promoting for instance renewable penetration (as for instance discussed below for the US ISO case) or for the strategic furtherance or protection of industrial development and diversification, as illustrated by the French example also described below.

The general consensus gleaned from a review of the literature on subsidized fuel is that it is extraordinarily inefficient, measured in terms of the stated aim. It actually broadens socio-economic inequalities because high income groups tend to benefit disproportionately (Arze del Granado et al., 2012), and because the energy waste, systematic resource misallocation (Fattouh and El-Katiri, 2013) and higher greenhouse gas emissions when applied to fossil-fuel generation technologies (Burniaux and Chateau, 2014), ensuing translate into a general and significant decline in social welfare (Plante, 2014).

Driven by the political opportunity afforded by falling oil prices, as well as improvement of renewables' learning curves, the global total of these subsidies declined by nearly half from

2012 to 2016 (Shirai and Adam, 2017). Pricing reform was undertaken in the form, for instance, of adjustments to bring prices in China in line with those prevailing internationally, or the gradual alignment of regulated prices to recover real costs. The outcome was a rise in oil product, natural gas, water and/or electric power in countries such as Saudi Arabia, Qatar, Bahrain and the United Arab Emirates (Matsumura and Adam, 2019).

Nonetheless and in spite of the obvious benefits to be reaped by eliminating subsidies (Coady et al., 2019), no significant or even minimal medium-term drop may be realistically expected, in light of recent reactions to rising oil prices: in 2018 fossil fuel subsidies totaled values last seen in 2014 (OECD/IEA, 2019). As later discussed, the energy price crisis in the EU started after the summer of 2021 is also fueling new policy measures aimed at "decoupling end user prices from market ones".

Generation-side fuel subsidies have routinely accounted for a substantial share of that total (Figure 1).

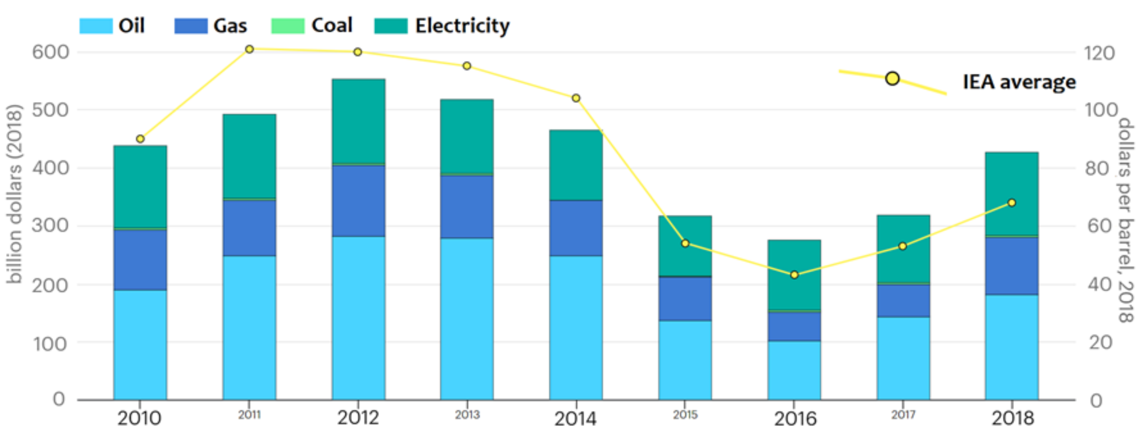

Figure 1. Subsidies for fossil fuel, 2010-18 (Matsumura and Adam, 2019)

2.2 Fuel-consumption subsidies and regional power market design in the international experience

Despite certain explicit but scantly specific commitments to gradually do away with fossil fuel subsidies[1], short- or medium-term phase-outs cannot be reasonably expected at this time. Insofar as such subsidies lower the price to the consumer of fossil fuel-generated electricity, they often have a bearing on regional power market design, a scenario not confined to scantly industrialized countries, as attested to by the examples described below.

Independent System Operators (ISO) markets in the US

Numerous energy subsidies exist in the U.S. tax code to promote or subsidize the production of cheap and abundant fossil energy (Coleman and Dietz, 2019). The United States provides a number of tax subsidies to the fossil fuel industry as a means of encouraging domestic energy

[1] In 2016 G-20 leaders reconfirmed a "commitment to rationalize and phase-out inefficient fossil fuel subsidies that encourage wasteful consumption over the medium term, recognizing the need to support the poor".

production. Additionally, numerous clean and renewable alternatives exist, which have become increasingly price-competitive with traditional fossil fuels.

The ISO markets implemented in the Regional Transmission Organizations (RTO) in the United States[2] have been subject for several years to a deep controversy sparked by merchant generators' concerns that state-subsidized resources — such as wind, solar and nuclear — depress market prices and make it more difficult for newer gas plants, for example, to compete.

In 2006 the PJM Interconnection introduced the Minimum Offer Price Rule (MOPR), setting a floor to the capacity auction price to prevent new generators from artificially bidding below-cost bids. In 2018, the Federal Energy Regulatory Commission (FERC) voted to bar subsidized power bids into the capacity auctions, but two years later, a new voting of the new configuration of FERC board reversed the previous decision. PJM revised its MOPR; under the new rules, renewable energy facilities and nuclear power plants are exempt from the MOPR, as will demand-response and energy efficiency programs, along with new natural gas-fired power plants. In a similar way, New York Independent System Operator's (NYISO) proposed in January 2022 to exempt clean energy resources from their MOPR (so-called "buyer-side mitigation"), while conversely, ISO-NE decided to "wholly support" the proposal to delay eliminating the MOPR until 2025 (Howland, 2022).

The MOPR keeps on being subject to significant controversy. As a way of example, it is worth quoting the disagreement expressed by one of the academic colleague who kindly reviewed of previous version of this article, arguing that the MOPR, "initially designed to to neutralize deliberate measures by certain states to manipulate the regional traded capacity market, ended up turning into something used by certain types of generation regionally (primarily gas-fired generators) to insulate themselves from the effects of demand from some parts of the region for certain other kinds of energy, from wherever it might be produced (which is a fundamental distortion of market supply and demand dynamics and infringes on legitimate state interests in deciding what kinds of energy resources they want to rely on without restricting where those resources are located or who owns them)."

Europe's internal market for electricity
Article 107 (1) of the Treaty on the Functioning of the European Union declares that State aid, in whatever form, which could distort competition and affect trade by favouring certain undertakings or the production of certain goods, is incompatible with the common market, unless the Treaty allows otherwise (BIS, 2011). According to Article 107 (1), state aid is granted by the State or through State resources, favoring certain undertakings or production of certain goods, distorting or threatening to distort competition, and affects trade between Member States. However, in the energy context, the 2008 State aid Guidelines on Environmental Protection included assessment criteria for state aid measures in 12 different areas, such as improving environmental performance beyond. A large part of expenditure assessed under the 2008 Guidelines served to promote energy from renewable energy sources. On 2014, the European Commission adopted new rules on public support for projects in the field of environmental protection and energy (European Commission, 2014). The guidelines

[2] See for example https://www.ferc.gov/electric-power-markets

aimed at supporting Member States in reaching their 2020 climate targets, while addressing the market distortions that may result from subsidies granted to renewable energy sources. The guidelines promoted a gradual move to market-based support for renewable energy.

Over the 2008-2018 period, the overall energy-related subsidies in the EU27 MS have increased by 67% (European Commission, 2020), see Figure 1.

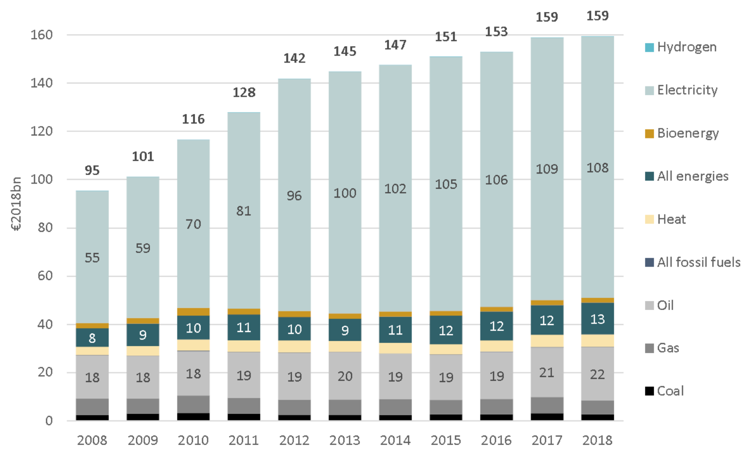

Figure 2. Subsidies by main fuels and carriers in the EU27 (European Commission, 2020)

However, in the EU context subsidies have not just been used to promote investment in new renewable resources. Further to French Act 2010-1488, new organization of electric power markets (*nouvelle organisation du marché de l'électricité, NOME)*, on access to the country's historic nuclear power (*Accés Régulé à l'Électricité Nucléaire Historique,* ARENH), the national power company EdF must reserve around 25 % of nuclear-fired power plant generation for other retail distributors at a regulated price lower than the wholesale market value (Lévêque, 2011). A first consideration (Creti et al., 2011) in connection with the provisions of the act is that the aforementioned access price is Government-, rather than market-determined. The underlying objective is to guarantee that any French customer can actually buy a portion of its consumption, backed by the large nuclear fleet of EDF, at a below-market price level. Secondly, it is not applicable to power market consumers outside France, for the act stipulates that supply is confined to the French domestic retail market and establishes fines for contravening that norm.

The French case cannot be considered as an exceptional case. The energy price crisis in the EU started after the summer of 2021 fueled new policy measures aimed at decoupling end user prices from market ones. For instance, On December 2021, the French, Greek, Italian, Romanian, and Spanish governments (2021) published a joint statement, proposing "to amend article 5 of the Electricity Directive in order to allow Member States to enforce regulatory mechanisms, designed at EU level, ensuring that final consumers pay electricity prices that reflect the costs of the generation mix used to serve their consumption." They alleged that these mechanisms would be "based on financial transfers between producers and consumers, [and] would have no effect on the functioning of the wholesale market."

On February 2022, Kyra Taylor (2022) leaked a draft communication from the European Commission (EC). In it, the EC raises "reasons to intervene in price setting in response to current energy market situation" and also opens the door to Member States "to capture a part of this additional infra-marginal rent by specific fiscal measures. However, such a measure would need to be carefully designed to avoid unnecessary market distortions."

Central American Regional Power Market

Central America's regional electricity market (*Mercado de Electricidad Regional, MER*) is also impacted by the existence of such subsidies (Dolezal, 2013). Hernandez Ore et al. (2017) report that Central American countries routinely exempt certain stages of electricity production from taxes or discount fuel prices. The six regional countries (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama) began to progressively integrate their power markets in 1996 under the conditions laid down in the framework treaty on the electric power market in Central America (*Tratado Marco del Mercado Eléctrico de América Central*) with a view to fostering regional power trading between countries, as well ultimately as region-wide investment in generation. Article 5 of the treaty specifies that the agents concerned (state- and privately-owned power companies) may freely and indiscriminately engage in the purchase and sale of electric power.

Andean Electric Power Market

Andean Community[3] Decision 816 on general framework for the sub-regional interconnection of electric power systems and intra-community power trading (*Marco General para la interconexión subregional de sistemas eléctricos e intercambio intracomunitario de electricidad*) institutes the regulatory framework for the Andean short-term regional power market (*Mercado Andino Eléctrico Regional de Corto Plazo, MAERCP*) as one of the elements of the regional Andean electric power market (*Mercado Andino Eléctrico Regional, MAER*). The MAERCP covers surplus energy trading, defining surplus energy to mean the "amount of energy not required to meet each country's domestic demand or maintain its security of supply, as determined by the national system operator further to domestic legislation". Article 4 specifically stipulates that the supply and demand curve prices applied to international electricity trading must not envisage any manner of subsidy whatsoever.

That provision is of particular significance in this regional market, where the cost of the fuel applied to electric power generation has commonly been the target of state intervention. A major share of the power generated with fossil fuels in Ecuador, for instance, has benefited from direct subsidies. All the gas extracted from Peru's Camisea[4] Lot 88 (10 TCF), in turn, may by law be used to meet domestic demand only and the wellhead price is subject to a ceiling laid down in the operating license agreement by and between the Camisea Consortium and Peru. To further the use of gas in power generation, the ceiling was initially stipulated to be US$ 1.0 MMBTU, as defined in both the Oil Field and Gas Field Machinery Producer Price Index and the Fuel and Related Products and Power Index (WPU05). The respective sum was

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[3] The Andean Community comprises Bolivia, Colombia, Ecuador and Peru.

[4] Data verified by Gaffney, Cline & Associates, international energy consultants, shows that the Camisea gas field reserves come to about 13.4 $*10^{12}$ feet^3 (360*109 m^3) of natural gas and 482 million barrels (76.6$*10^6$ m^3) of natural gas liquids (NGL) (Wikipedia).

raised in 2014 to around US$ 1.9 MMBTU. Inasmuch as gas transmission fees for electric power generators is set at less than US$32/Mil m3, the highest end price reasonably foreseeable would be a scant US$3 MMBTU, which is much lower than the value prevailing on the international marketplace.

Gulf Cooperation Council regional interconnection

The Gulf Cooperation Council (GCC) provided for energy trading between six states (Bahrain, Oman, Kuwait, Qatar, Saudi Arabia and the UAE) under the umbrella of its regional power interconnection in 2009. The GCC Interconnection Authority (GCCIA[5]), in turn, concluded from its studies that power trading among them in 2015 could potentially amount to over US$ 500 million and the more than US$ 25 billion across a 25 year horizon. Although at this writing the GCC Power Exchange runs continuous day-ahead and intraday markets (GCCIA, 2019), even against the backdrop of its modest interconnection capacity, GCC interconnection trading potential is underexploited. Bilateral “in-kind” and “in-cash” model contracts have accounted for a major share of power trading in the region in the last few years.

One of the foremost reasons cited to explain that situation is the market distortion induced by subsidies, viewed as a significant hurdle to the institution of a fully operational power market capitalizing on the GCC interconnector (IMF, 2017; Mollet, 2018; Wogan, 2019). In most MENA and some Gulf countries electric power generators are able to purchase gas and oil at less than the going market price (Benali, 2019). Low-cost energy commodities are often deemed a basic civil right and controlling prices a way to redistribute oil producers’ natural resource wealth (IMF, 2017).

In the last few decades, a fair number of power pool initiatives have been undertaken in Africa, whilst the South African Power Pool (SAPP) has been fostering an ambitious regional power market for over 10 years.

Fuel subsidies for generators not only hinder efficient regional trading but also stymie technological development. As international power trading seeks to implement more sustainable models, the existing paradigm will need to change, albeit with utmost care and at a cautious pace. In a context in which any number of power systems will continue to feature subsidies, they should be designed to ensure they do not distort the economic message transmitted by electric power prices. Reform in that regard is of particular importance in jurisdictions where power demand per capita is high, primed at least in part by very high generation-side subsidies.

In terms of regional power integration, alternatives to the widespread practice of designing these subsidies as a discount on the fuel price internalized by power generators could well and meaningfully enhance market efficiency. Suitably handling the various forms of generation-side fuel subsidies is instrumental to ensuring due regional market roll-out in many jurisdictions, as well as to maintain the ones that have been functioning already for years, as it is the case of the European electricity market just discussed.

[5] www.gccia.com.sa/

In some cases, as it is the US case introduced above, the Minimum Offer Price Rule aims at preventing subsidized generation from competing in an advantageous position beyond borders, in the ARENH or the GCC cases, the objective of the regulators is to avoid that the subsidies provided to reduce energy prices for local demand are exported.

One of the key elements of regional markets is obviously the bidding and clearing mechanisms. In the presence of any sort of subsidization policy, designing mechanisms to optimize price calculation subject to these higher order constraints happens to be instrumental. Along these lines, after a brief introduction to the most common mechanisms in place in organized power markets to enable members to express their buy/sell intentions, the section below describes a proposal for a novel bidding format and clearing method that would accommodate provisions enabling regional market participants to confine access to fuel subsidies to domestic demand.

3 PROPOSED NEW BIDDING FORMAT FOR DIFFERENTIAL PRICING OF EXPORTS

The accommodation of baseline national circumstances in regional power market design is imperative to successful integration of the respective domestic power systems. While ideally all the conditions that would theoretically optimize net welfare should be instituted, at least in the first stages of the development, market roll-out should not radically challenge states' or countries' sovereign rights over natural resources and domestic energy policies, electric power pricing in particular.

Wogan et al. (2019) contend that maintaining fuels used for electricity generation at a low price, which varies by country, is "a key barrier to regional movements of electricity because it is not likely that a country wants to incur the costs of exporting the value of its subsidies".

The new bidding format proposed here is obviously unable to reverse the economic inefficiencies stemming from a failure to factor in the real opportunity cost of fuel, regionally speaking. It does, however, address the reluctance observed among many market members to eliminate subsidies designed to lower generation-side power prices for their local demand.

3.1 Bidding formats in organized power markets

The parameters submitted by market participants for subsequent clearing constitute what are known as bidding formats. In addition to expressions of intention to buy/sell power, they include information on agents' specific characteristics (such as capacity to physically respond to market demand or, in hydro-plants or others fueled by a limited resource, to gradually raise the price of the energy stored in their reservoirs). The approaches adopted by existing power markets to enable participants to specify their operating constraints such as start-up, minimum output or ramp rates vary widely (Herrero et al., 2020).

In the United States, generating units can explicitly stipulate their operational (and opportunity) costs, such as start-up expenses, as well as their technical constraints, including ramp rates for instance, in multi-part offers.

That differs substantially from the procedure adopted by the All NEMO (Nominated Electricity Market Operators) Committee, the group of bodies that jointly match orders and offers on the EU's day-ahead and intraday integrated power markets and allocate the available cross-zonal capacities. In pursuit of a system that would combine the benefits of multi-part and direct auction bidding (simply matching quantity/price pairs per time interval), hybrid alternatives have been designed to accommodate complex offer conditions, see the description of the EUPHEMIA market clearing algorithm in NEMO Committee (2019).

The practical implications of that approach entail the inclusion of certain heuristic constraints in the offer format which in fact refer not to individual constraints or cost components per se, but to the combined effect of several, such as in the EU's PX block bids. With that device agents can communicate the hourly intervals in which they are willing to generate power in conjunction with the mean price they would accept to commit to such output. The NEMO Committee defines block orders in an Exclusive group as follows:

> *An Exclusive group is a set of block orders for which the sum of the accepted ratios cannot exceed 1. In the particular case of blocks that have a minimum acceptance ratio of 1 it means that at most one of the blocks of the exclusive group can be accepted. Between the different valid combinations of accepted blocks the algorithm chooses the one which maximizes the optimization criterion (social welfare).*

EUPHEMIA clearing also envisages so-called merit orders to rank orders in the respective bidding zones, in which the highest priority for acceptance is accorded the order with the lowest merit number. The NEMO Committee (2019) document states in this regard that "when, within an uncongested set of adjacent bidding zones, several merit orders have a price that is equal to the market clearing price, the merit order with the lowest merit order number should be accepted first unless constrained by other network conditions".

3.2 Export bids

The "export bid" bidding format proposed hereunder, designed along the lines of the aforementioned formats, would enable generating units to offer their output at different prices on different regional nodes. The respective algorithm, in turn, would ensure that the sum of all the purchase orders for the power offered would not exceed maximum power plant production at any given time.

The underlying intention is to allow generating units to express a willingness to sell their output at one price in the local/domestic node or zone and at another for exports. Inasmuch as the structure of the bidding format is fairly straightforward, no further details are deemed necessary. Adaptation of the clearing algorithm to handle this new format is set out in sub-section 3.3 below.

3.3 Clearing market algorithm design to accommodate export bids

The scheme in Figure 2 depicts an example of how export bids could be factored into the regional market algorithm. In a regional power market integrating three systems, *A, B* and *C*, the respective interconnectors would be Iab and Ibc. For the sake of the present argument, area

A is assumed to comprise three generating units (Ga_1, Ga_2, Ga_3), and areas *B* (Gb_1, Gb_2) and *C* (Gc_1, Gc_2), two each.

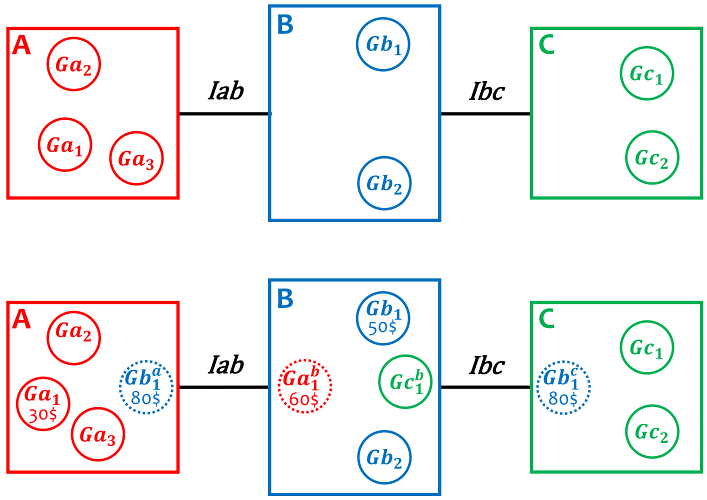

Figure 3. Example of inclusion of export bidding format in regional market algorithm

The export bidding format proposed aims to enable generating unit Ga_1, for instance, to offer 100 MW at \$30/MWh in zone *A* and the same amount at \$60/MWh in zones *B* and *C*, subject to not exceeding the total 100 MW bid.

As Figure 2 shows and further to the description that follows, the algorithm would replicate the exporting units on both sides of the interconnector. Further to this simple procedure (bearing in mind as well its impact on maximum interconnector capacity as explained below), the algorithm would readily accommodate the application of differential pricing for domestic and export power.

Formulation of the market clearing algorithm

In unit commitment (UC) and economic dispatch (ED) models, power supply and demand are balanced to optimally match power generation and demand. Given that although both optimize each unit's output while UC also makes provision for their start-up and shut-down criteria, ED is programmed linearly (LP) and UC as a mixed-integer linear program (MILP).

Dispa-SET[6] UC-MILP architecture was used for these intents and purposes, adapting the model variables and expanding the formulation to perform the present exercise.

Total regional system cost, i.e., the sum of the operating costs of all the member zones, is minimized by defining the objective function. Equation (1), in turn, finds each zone's operating cost as the sum of the costs of keeping units running plus the cost of unmet demand, which includes ramping constraints and minimum upward and downward reserve requirements in addition to no-load, start-up, shut-down and variable costs. Load loss due to load shedding forms part of the cost of unmet demand.

[6] Dispa-SET, an open-source UC and ED model, is being developed by the European Commission's Directorate General Joint Research Centre as both an MILP and an LP. See Pavicevic (2019), Annex, for a full description.

Consequently, the operating cost (OC) function is as shown below:

$$OC_{n,t} = \sum_{u \epsilon U}(C_{u,t}^{var} + C_{u}^{fix} \cdot l_{u,n} + C_{u}^{start} \cdot l_{u,n} + C_{n,t}^{shed} + C_{n,t}^{VOLL}) \qquad (1)$$

where $C_u^{fix}, C_u^{start}\ and\ C_u^{ramp}$ are the fixed, start-up/shut-down and ramping costs, respectively, while $C_{n,t}^{VOLL}$ represents lost load costs.

$l_{u,n}$ is a binary parameter {0,1} which indicates whether or not the unit *u* is located in zone *n*. In this model "export bids" are expressed as $C_{u,t}^{var}$, i.e., unit *u*'s variable costs in time interval *t* (or alternatively, a bid specifying two variable costs depending on the location of the selling node):

$$C_{u,t}^{var} = C_{u,t}^{var} \cdot P_{u,n,t} \cdot l_{u,n} + \sum_{\substack{nn \in \widetilde{N} \\ nn \neq n}} C_{u,t}^{varD} \cdot P_{u,n,t} \cdot l_{u,nn} + \sum_{\substack{nn \notin \widetilde{N} \\ nn \neq n}} C_{u,t}^{varE} \cdot P_{u,n,t} \cdot l_{u,nn} \qquad (2)$$

where $C_{u,t}^{varD}$ is the local dispatch price (which takes the subsidized fuel price into consideration) applied within the unit's zone (a given country may be divided into different zones) or country, whereas the fuel price, $C_{u,t}^{varE}$, denotes the export price.

$P_{u,n,t}$, in turn, is the fraction of unit *u*'s output supplying zone *n* at time *t*: in other words, the portion of plant *u* located virtually in another country where it does not want to apply the domestic subsidy, is calculated as shown in Equation (3):

$$P_{u,t} = \sum_{n \in N} P_{u,n,t} \qquad (3)$$

4 CASE STUDY: THE GULF COOPERATION COUNCIL REGIONAL MARKET

A full-scale case study was simulated assuming interconnection among all GCC member states' power systems. Under no circumstances should the exercise be interpreted as an attempt to forecast the future operation of the regional market. Rather, the model was chosen merely to illustrate the utility of the market design proposed here to clear the ground for trading start-up.

The system as a whole comprises 13 zones (Figure 3): eight in Saudi Arabia and one each in the other five GCC countries, Kuwait, Bahrein, Qatar, UAE and Oman.

The case study and input data (generation mix, operating costs and local fuel subsidies) were sourced as listed in the Annex.

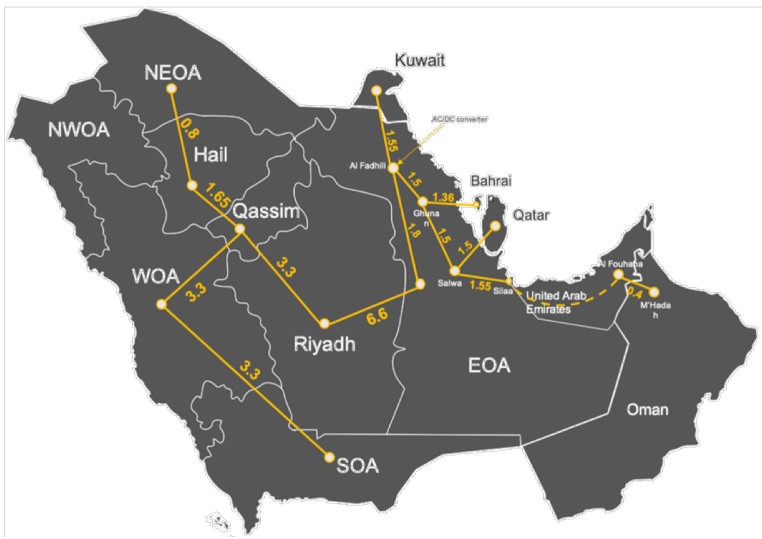

Figure 4. GCC network transmission capacity (GW)

4.1 Model assumptions

The one-week horizon and hourly granularity assumed for the simulation were applied to an MILP accommodating start-up and shut-down criteria. The integer clustering procedure described by Pavicevic et al. (2019) was deployed to minimize computing time while ensuring robust representation of convex costs and constraints, such as start-up and shut-down decisions and ramping. The outcome of clustering plants by technology, fuel type and zone was a reduction in the number of total units from 1018 to 777.

Fuel subsidies in the GCC

No general consensus has been reached on how to measure generation-side fuel subsidies (Charles et al., 2014; Wogan et al., 2019). Under the simplest procedure, the co-called "price-gap" method, the difference in the price paid by the generator and a reference (international or benchmark) price is calculated, adjusting for shipping and distribution costs in oil-importing countries, to estimate the opportunity cost of selling energy products at lower than international market prices.

Figure 4 below graphs the gaps between the international price of four fuels and the price actually in place in the region's six countries as calculated with this method.

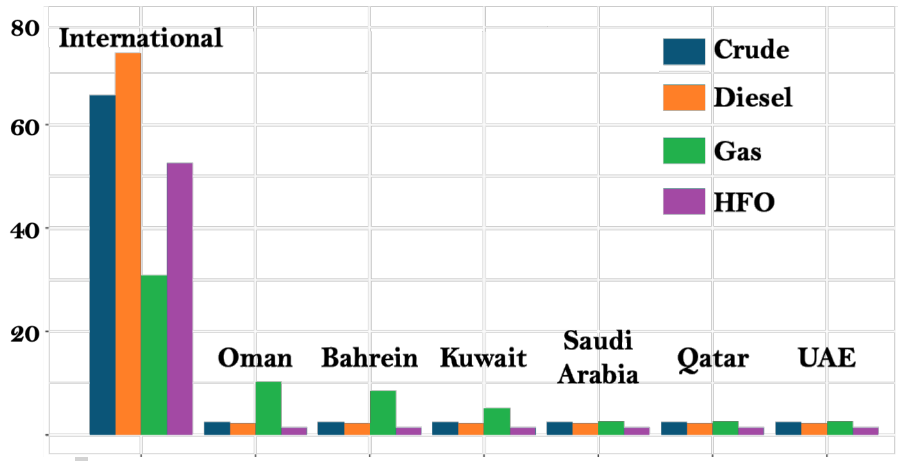

Figure 5. Mean difference in international and applied fuel prices, price-gap method

The subsidies, for gas in particular, vary from country to country, while the inference that can be clearly drawn from the data is that in light of such substantial subsidies, no manner of cross-border trading is conceivable.

The nearly even application of subsidies to all fuels in the six participant countries in the form of the discount on the amounts priced in by power generators to calculate unit commitments leaves no room for GCC members to capitalize on the efficiencies afforded by trading over the interconnector. Where all six discount the four primary fuel prices by 80 %, for instance, no trading or therefore efficiency gains would be forthcoming. No country able to produce electric power more efficiently than its neighbors should be reasonably expected to engage in cross-border trading at the subsidized price.

4.2 Simulation results

This article aims to show that the method proposed, as a second-best but instrumental approach to the problem, could encourage integration among countries where power generation is generously subsidized. Two scenarios were compared:

- Scenario A: full market integration in which all countries eliminate all subsidies. This scenario is highly unlikely, inasmuch as such a measure would be socially unacceptable.
- Scenario B: application of subsidies currently in place in all countries to domestic demand but not to power exports to transition between the status quo in which no participant exports subsidized electric power and scenario A, full market integration at some future date.

The results for one winter and one summer week are graphed in Figure 6.

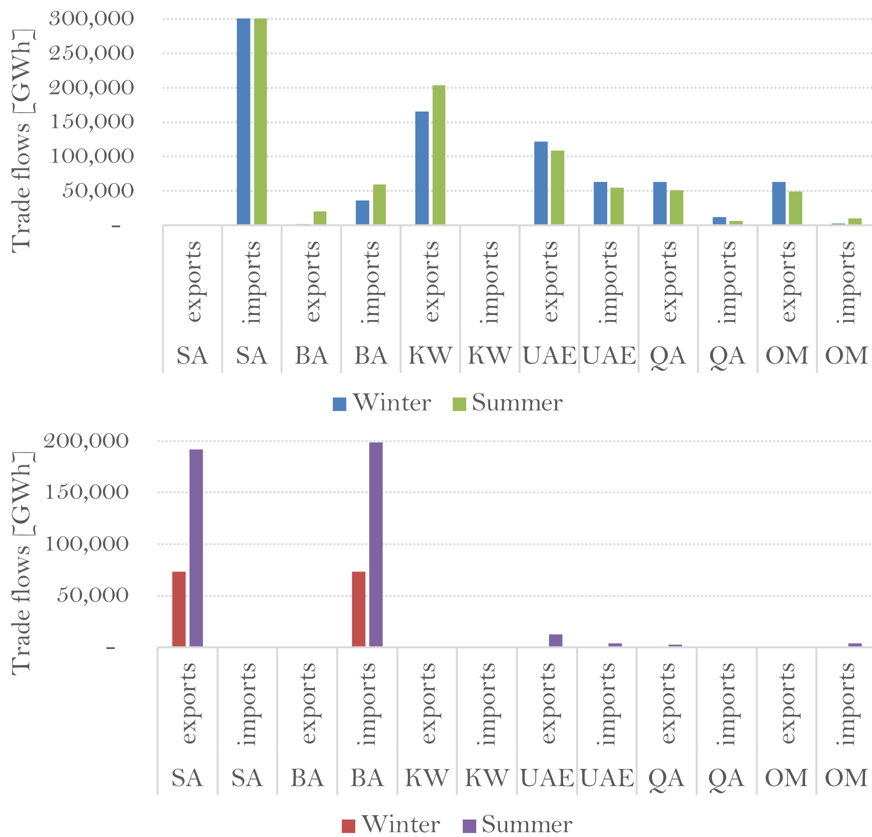

Figure 6. Power exports and imports by country: scenarios A (above) and B (below)

Trading intensity would be maximized where all subsidies are lifted (scenario A). All six countries would take part in this international exchange, with Saudi Arabia as the predominant importer, for its generation portfolio is characterized by a prevalence of aging and inefficient oil-fired plants. In the absence of subsidies, four of the remaining five countries (the exception being Bahrein) would generate power more cheaply than Saudi Arabia. In contrast, if market clearing envisages a bidding format such as proposed and even if the subsidies are not lifted, some international trading would take place, primarily between two pairs of trading partners: Saudi Arabia would export power to Bahrain and the UAE to Oman. That much lower intensity relative to scenario A would be explained by the high subsidies applied, primarily to oil and its derivatives. In light of the wide gap between international and subsidized fuel prices, trading is close to negligible, although not impossible as the example shows. Oman would import electricity from the UAE when the variable subsidized cost of running its marginal units is higher than the non-subsidized cost of power generation in the Emirates. When the oil-fired fleet is heavily subsidized in all GCC nations, Saudi Arabia's most competitive gas-fired units could meet part of the demand in Bahrain.

The foregoing analysis would be incomplete, however, without a comparison of total production costs for the region as a whole and their country-by-country breakdown. Real production costs were consequently estimated assuming subsidy-induced distortion would be absent in international fuel prices. The first finding was that generation costs would be higher in the absence of market integration (Figure 7).

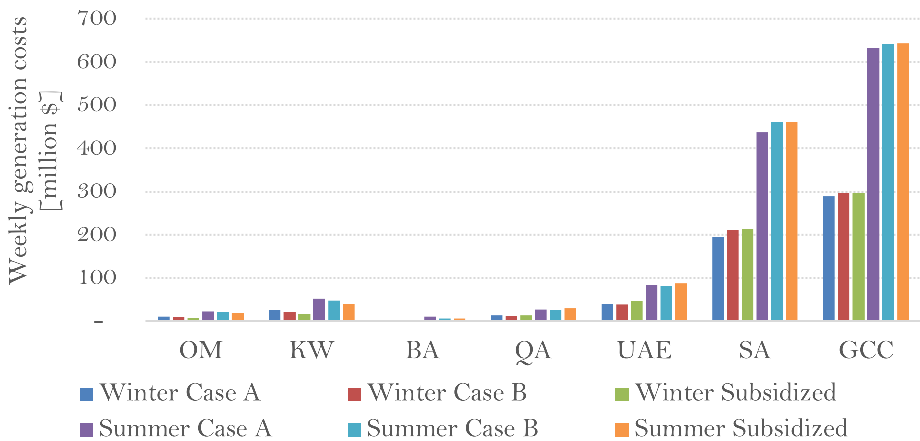

Figure 7. Generation costs by country and for the region as a whole

They would be around 1.7 % lower in summer and as much as 3 % lower in winter under scenario A, whereas under proposed scenario B they would lie about halfway between those two extremes.

On the country scale, higher production costs are indicative not of a decline in system performance but of a rise in the output of more efficient units able to export the power generated. The largest participant, which also has the most sizeable fleet of inefficient subsidized units, would benefit from the savings deriving from integration. The solution proposed, then, as discussed earlier, smooths the way for gradual market integration until such time as all GCC participants lift their subsidies.

5 CONCLUSIONS AND POLICY IMPLICATIONS

Although the regional integration of electric power systems is instrumental to maximizing power generation efficiency in both the short and long term, in a number of jurisdictions generation-side fuel subsidies constitute a formidable obstacle to successful market operation. Solutions are required to enable regional markets to adapt to the presence of subsidies. The present article reviews the issue, suggesting an initial mechanism that would enhance regional economic dispatching efficiency and presenting market design as a useful tool for eliminating or at east lowering that hurdle. By implementing the bidding format and market clearing method proposed, countries could transition to integrated regional markets while gradually paring down their subsidies.

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ANNEX: MODEL DATA SOURCES

All the data on loads, generation and networks refer to the year 2016. The Saudi Electricity Company (SEC) furnished the hourly loads per zone in Saudi Arabia and GCCIA the values for the other GCC members. Analogously, inter-Saudi transmission line capacity was provided by SEC and the data for the interconnector as a whole by GCCIA. Information on the generation mix, gathered from SEC for Saudi Arabia and the S&P Global Platts' World Electric Power Plant Database for the other GCC members, was subsequently processed and adapted for model input.

Variable costs, the sums used here to define export prices, were referenced to international fuel price forecasts and more specifically to the World Bank's estimate of fuel costs for 2025:

- Crude Oil: \$48.9/bbl, or \$8.43/MMBtu.
- Natural Gas: \$3.8/MMBtu. The European price, one major destination of GCC gas exports, is expected to rise to \$4.8/MMBtu, from which \$1/MMBtu was subtracted to factor in the approximate cost of shipping the gas from Qatar to the UK (Rogers, 2018).
- Heavy fuel-oil and diesel: \$6.75/MMBtu and \$9.49/MMBtu, respectively. Given that over the long term the price of these two derivatives courses in close parallel to the price of crude oil, the differential suggested by Nachet and Aoun (2015) was adopted.

Efforts to gradually lift these subsidies in recent years notwithstanding, fossil fuels are generously subsidized for power generation in all GCC countries. The International Energy Agency estimates the sum of such subsidies to have ranged from 0.2 in Qatar to 5.8 billion USD in Saudi Arabia in 2019. The data used to estimate the country-by-country totals for natural gas and oil and its derivatives given in Table i below was drawn primarily from Cote and Wogan (2016).

Table i. Generation-side fossil fuel subsidies by energy source and GCC country

	Bahrain	Kuwait	Oman	Qatar	Saudi Arabia	UAE
billion USD (IEA, APSR)	0.56	3.12	0.92	0.20	5.82	0.58
Natural gas	30 %	25 %	15 %	15 %	15 %	15 %
Oil and derivatives	85 %	35 %	75 %	20 %	20 %	20 %

The fuel costs and subsidies were assumed to remain constant year-round and the systems to be outage-free. The renewable resource availability factors for a typical meteorological year (TMY) were calculated from European Commission Photovoltaic Geographical Information System (PVGIS) data, while load shedding costs were set at a constant \$1000 per MWh.

Contact.

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