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Opportunity in a Crisis: The Economic Benefits of the Renewable Energy Transition in Lebanon

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This policy paper aims to inform stakeholders, policymakers, and funders on Lebanon's current energy transition, focusing on the rapid adoption of private solar installations, without which the economic, social, and political recovery of the country will be unattainable. It discusses the structural and situational causes of the sector's collapse, which have led to a swift increase in the deployment of solar panels. The paper highlights the opportunities presented by this trend, as well as some of the challenges arising from an unregulated, privately initiated, and geographically concentrated deployment. In this regard, the adoption of Law No. 318/2023 on decentralized renewable energy could constitute a pragmatic solution for a way out of the crisis. Nevertheless, its effective implementation and the unlocking of essential funds to restore energy production and achieve financial stability in the sector demand a series of urgent reforms, several of which are proposed in the conclusion.

Introduction

On August 17, 2024, Electricité du Liban (EDL) experienced yet another blackout of all production units in its thermal power plants due to fuel shortages and delays in the latest shipment under the 2021 Lebanon-Iraq swap agreement. This occurred despite EDL — the main source of Lebanon's electricity production, transportation, and distribution — having made a modest recovery by mid-2023, amid the energy crisis that worsened after the country's 2020 sovereign default.

Indeed, the energy sector's crisis is structural, and presents challenges that are technical, financial, institutional, and political. There is a significant gap between the national supply and demand, estimated at 2,250 MW on average in 2021.[1] Contributing factors include fluctuations in the price of imported fossil fuels—which account for 97% of the Lebanon's energy mix in 2021[2]—fuel theft, and unpaid bills, but also from the financial crisis and the collapse of the exchange rate,[3] which led to hyper-inflation in the cost of importing fossil fuels for EDL and households.

Other challenges include the very delicate political situation of this multi-confessional country, where political balance rests on the 1943 compromise,[4] and which has still not managed to form a government since the 2022 elections. Moreover, the influence of certain 'profiteers of the crisis,' such as the owners of diesel-powered generators that proliferated with the energy crisis, represents a significant obstacle to

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HRW. 'Cut Off from Life Itself' Lebanon's Failure on the Right to Electricity. July 2023. In: https://www.hrw.org/sites/default/files/media_2023/03/lebanon0323web.pdf

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IEA. Energy system of Lebanon. Consulted in 2024. In: https://www.iea.org/countries/lebanon

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The exchange rate had been pegged by the Lebanese central bank at USD 1 = LBP 1,507.5 since 1997. However, with the onset of the economic crisis, extreme fluctuations on the parallel currency market led the exchange rate to exceed LBP 100,000 per USD 1. This discrepancy is particularly problematic because depositors are forced to withdraw their funds at the official rate, which is significantly lower than the parallel currency market. In an attempt to narrow this gap, the Banque du Liban raised the exchange rate on its Sayrafa platform for commercial banks to LBP 89,500 per USD 1 in December 2023. In: https://www.lorientlejour.com/article/1361472/livre-libanaise-le-taux-de-sayrafa-virtuellement-aligne-sur-celui-du-marche.html

4
This unwritten agreement, traditionally described as the founding charter of Lebanon, led to the confessional distribution of public offices within the Lebanese state.

the implementation of reforms. Financial recovery for EDL and structural reforms of the energy sector are also conditioned on the absence of political blockages and a return to macroeconomic stabilization.

In this context, the intensified use of private solar panel installations in response to the crisis, with micro-grid projects proliferating in recent months in rural and urban areas, represents an opportunity for the country. While initiatives to replace fuel with natural gas or to implement larger-scale renewable energy projects appear to be on hold currently,[5] integrating renewable energy into the EDL distribution network could provide a pathway to financial stability for the company. This integration, over time, could enable the necessary capital injections to boost its production capabilities and initiate extensive solar and wind projects under the Independent Power Producers (IPP) model.[6] By leveraging its distribution network for this purpose, EDL could set Lebanon on a course toward sustainable energy development.

The primary goal of this Policy Paper is to explain some of the current dynamics within the energy sector, particularly the state of EDL and the roles of other key stakeholders, such as diesel generator owners, who pose significant challenges. The scope for policy alternatives to address these issues is limited by persistent political and institutional stalemates, as well as the nation's fiscal insolvency. Efforts by the IMF and the World Bank to initiate reforms, especially regarding EDL, have not yielded the desired outcomes. This failure can be attributed in part to a lack of engagement with the complex web of interests and environmental factors affecting the various actors involved. Therefore, simple and pragmatic short-term reforms should focus on restoring EDL's production and financial balance by integrating off-grid renewable energy sources into EDL's network, creating the necessary conditions for unlocking essential funding.

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For example, the failure to deploy a floating FNL regasification terminal at the World Bank's Zahrani energy interconnection plant, which was to bring Egyptian gas to Lebanon's Deir Ammar power plant.

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An Independent Power Producer (IPP) can be defined as a privately-owned entity that owns or operates electricity-generating facilities, selling power either to the national grid, where permitted by regulations, or directly to end users through Power Purchase Agreements (PPAs).

I Structural weaknesses of an outdated network amid crisis

To assess the significance of the problem, it is appropriate to briefly revisit the situation of the electricity sector, particularly of EDL—a symbol of the dilapidation of public services and governance failure—before the crisis. The current crisis has only accelerated the collapse of EDL, which has forced most businesses and households to turn to electric generators to access power, creating significant barriers to reform.

EDL: The failure of post-civil war reconstruction

The failures of the power sector in Lebanon, where shortages are a daily occurrence, and of the state-owned power utility EDL are old and structural. The period of reconstruction that followed the Lebanese civil war (1975-1990) and the destruction of nearly all of EDL's generation, transmission, and distribution assets did not allow for the remediation of EDL's pre-existing problems and inefficiencies.[7] EDL suffered for decades from chronic underinvestment in its generation capacity, high losses in transmission and distribution, blockages of fuel imports, as well as corruption and clientelism within the sector.

Before the beginning of the crisis that started with Lebanon's default on its sovereign debt, the gap between electricity supply and demand was already estimated at 1.5 GW (not taking into account Syrian and Palestinian displaced persons on the territory).[8,9] Moreover, EDL has faced annual deficits ranging from US$1.5 to 2 billion over the past decade. Approximately 46% of Lebanon's public debt, which today amounts to 509% of GDP,[10] results from treasury transfers to EDL, costing public finances around US$43 billion between 1993 and 2020.[11]

The overhaul of the Lebanese electricity network, initiated after the civil war, also profoundly reflects the sectarianism characterizing the country, with specific arrangements in areas fragmented according to communal cleavages. Electricity is thus leveraged as a critical resource to protect for political and religious elites who have instrumentalized it for decades. As such, the deployment of electrical infrastructures is part of a dynamic of political and sectarian control. For example, the Shia regions of Baalbek, Sour, and Zahrani, the Christian areas of Zouk and Hraycheh, the Druze region of Jiyeh, and the Sunni area of Deir Ammar, each benefited from the installation of thermal power stations after the conflict.[12]

This same logic was applied in the 2012 division of the distribution network into three zones (excluding Jbeil and Zahlé), allocating them to three private companies on which EDL relies to upgrade the distribution network through the installation of smart meters and to improve bill collection and customer service.[13] In the north, the company Bus, owned by a Christian entrepreneur, was charged with the Christian zones, while parts of Beirut and the Bekaa, predominantly Sunni, were entrusted to KVA, a company linked to the former Prime Minister Rafik Hariri.[14] The southern zone was allocated to the Mrad group, belonging to an entrepreneur from the Shia and Druze region.[15]

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Michael F. Davie, 'La gestion des espaces urbains en temps de guerre circuits parallèles à Beyrouth,' Reconstruire Beyrouth, Les Paris sur le possible, 1991, p. 172, https://www.academia.edu/9606626/La_gestion_des_espaces_urbains_en_temps_de_guerre_circuits_parall%C3%A8les_%C3%A0_Beyrouth (accessed January 27, 2023).

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The number of displaced Syrians in Lebanon is estimated at over 2 million, in addition to 300,000 Palestinian refugees (Courrier International), for a total of 5.4 million Lebanese (DG Trésor, July 2024).

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Ahmad Ali. DISTRIBUTED POWER GENERATION FOR LEBANON, Market Assessment and Policy Pathways. May 2020. In World Bank. https://documents1.worldbank.org/curated/en/353531589865018948/pdf/Distributed-Power-Generation-for-Lebanon-Market-Assessment-and-Policy-Pathways.pdf

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Ayoub, Marc. Rizkallah, Pamela. Abi Haidar, Christina. Unbundling Lebanon's Electricity Sector. UCL. September 2021. https://www.ucl.ac.uk/bartlett/igp/sites/bartlett_igp/files/unbundling_lebanons_electricity_sector_research_report.pdf#page24

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Verdeil, Éric. La crise électrique du Liban : une lecture géographique. Moyen-Orient, 2022, 56-61. hal-03814481

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US Department of State. 2024 Investment Climate Statements: Lebanon. 2024. In: https://www.state.gov/reports/2024-investment-climate-statements/lebanon/

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Verdeil, Éric. La crise électrique du Liban : une lecture géographique. HAL Sciences. November 2022. In: https://hal.science/hal-03814481/document1

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Ibid.

The goal of this modernization was to equip the network with new meters to eradicate non-technical losses (i.e., fraud and unpaid bills), which have also plagued EDL's finances since the civil war. At that time, the collapse of the state and the Syrian and Israeli occupations facilitated the generalization of these fraudulent practices. In the 2000s, electricity theft, including unpaid bills and un-billed consumption, was estimated at about 10% in Beirut. In the peripheral regions of northern Bekaa, the center, and north Lebanon, it can reach up to 60%.[16]

A UNDP/MoE report published in 2015[17] highlights the contrast between the capital and peripheral regions, which are poorer and facing significant infrastructure deficits. Indeed, fossil fuel subsidies—which cost the country up to US$3 billion annually until 2022[18] and contributed to draining the central bank's reserves[19]—have disproportionately benefited the wealthiest segments of the population, due to their higher consumption levels, as is the case in Beirut. This contrast underscores that the issue of electricity transcends the mere challenge of sectarian territorial control to highlight developmental inequalities between center and periphery.[20]

In addition to these challenges, Lebanon suffers from the consequences of its heavy dependence on hydrocarbon imports,[21] due to its low domestic energy production. This dependence exposes the country to political pressures from its neighbors and is particularly reinforced in the context of its currency collapse, making it extremely difficult for EDL to purchase the necessary fuels. Although Lebanon has an offshore gas field, geopolitical challenges and the lack of investment prevent its exploitation. These structural weaknesses are exacerbated by the financial crisis affecting the country and the 2020 explosion at the Port of Beirut, which resulted in the destruction of Achrafieh's dispatching center.

Despite the current challenges, it is important to remember that this situation is not irreversible. In the 1960s, Lebanon was a net exporter of electricity, largely due to its hydroelectric production.[22] However, currently, most of Lebanon's power generation facilities are outdated and largely non-operational. The country has seven thermal power plants[23] with a total installed capacity of 1,800 to 2,000 MW,[24] but actual production was only 800-900 MW in 2021.[25] Additionally, Lebanon has 18 hydroelectric units[26] with a total installed capacity of 270 MW,[27] but by 2021, their production had dropped to just

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Verdeil Eric. Electricité et territoires : un regard sur la crise libanaise. Revue Tiers Monde. February 2009. In: https://www.cairn.info/revue-tiers-monde-2009-2-page-421.htm

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UNDP/MoE. Fossil Fuel subsidies in Lebanon. May 2015. In: https://climatechange.moe.gov.lb/viewfile.aspx?id=218

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Cuyler, Zachary. Competing Visions for Rebuilding Lebanon's Collapsing Energy Sector. Middle East Research and Informaiton Project. August 2022. In: https://merip.org/2022/06/competing-visions-for-rebuilding-lebanons-collapsing-energy-sector/

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Chehayeb, Kareem. The Weight of Lebanon's Unsustainable Subsidies Program. The Tahrir Institute for Middle East Policy. April 2021. In: https://timep.org/2021/04/30/the-weight-of-lebanons-unsustainable-subsidies-program/

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Éric Verdeil. La crise électrique du Liban : une lecture géographique. HAL. November 2022. In: https://hal.science/hal-03814481/document

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IEA. Energy system of Lebanon. Consulted in 2024. In: https://www.iea.org/countries/lebanon

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Iskandar, Amine. L'eau pour sauver le Liban 1/3. Ici Beyrouth. June 2022. In: https://icibeyrouth.com/liban/85078

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Located in Deir Ammar, Zouk Mosbeh, Baalbeck, Jiyé, Tyre, and Zahrani.

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Hage-Boutros, Philippe. Ricour-Brasseur, Julien. Comment EDL gères le rationnement de son carburant. June 2021. L'Orient le Jour. In : https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.lorientle-jour.com%2Farticle%2F1265231%2Fcomment-edl-gere-le-rationnement-de-son-carburant.html&psig=AOvVaw1t7pCLSoopk_BaYYQYSf6D&ust=1723197897840000&source=images&cd=vfe&opi=89978449&ved=0CBQQjhxqFwoTCKCr5caS5YcDFQAAAAAdAAAAABAQ

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Ibid.

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The Litani group includes the Anan, Markaba, Joun, and al-Soubah plants. The Nahr el-Bared group includes Nahr el-Bared 1 and Nahr el-Bared 2. The Nahr Ibrahim group includes Nahr-Ibrahim 1, Nahr-Ibrahim 2, and Nahr-Ibrahim 3. The Qadicha group comprises four plants: Blaouza, Abou-Ali, Mar-Elychaa, and Bcharré. Additional plants are located in Richmaya, Chekka, Hrach, Zahlé, and Tannourine.

27
Ibid.

48 MW.[28] Since 2021, the energy situation has not significantly improved, with episodes of near-blackouts in early 2023 and more recently in late July 2024. By the fall of 2024, EDL is expected to restore its pre-blackout production levels, with output from the Deir Ammar and Zahrani thermal plants projected to reach between 350 and 400 MW, supplemented by an additional 70 MW supplied by hydroelectric capacity.[29] Despite these efforts, the restored capacity will still fall short of the country's demand, which in 2021 was estimated to range between 3,000 and 3,400 MW during the summer peak.[30]

Mounting pressures lead to EDL's collapse

Following the country's sovereign default in March 2020, Lebanon sank into a profound multidimensional crisis. The depreciation of the exchange rate led the Banque du Liban (BDL, Lebanon's central bank) to freeze the bank assets of Lebanese citizens to prevent the total collapse of the banking system. Access to the dollar was also tightly rationed, prioritizing the defense and stabilization of the parallel market exchange rate. Until recently, the central bank applied a discretionary exchange policy towards EDL. The electricity pricing mechanism was based on the 'Sayrafa' platform rate, which was lower than the black-market rate, but included a 20% surcharge, posing a significant exchange rate risk to EDL.[31]

After being both severely affected by and contributing to the country's macroeconomic imbalances, EDL's ability to produce and distribute electricity was severely impaired in mid-2021, following the cessation of budgetary transfers and tariffs frozen at levels insufficient to cover production costs. In the first half of 2022, EDL provided an average of half an hour to a maximum of one hour of electricity per day to the capital Beirut. According to the results published by the company for the period 2019 to 2022, EDL recorded cumulative losses of LBP 5.6 trillion between 2019 and 2022, exacerbated by the depreciation of the Lebanese pound against the US dollar.[32]

After a total blackout in early 2023, EDL began to increase its electricity production to 4 hours per day on average[33] by purchasing commercial fuel and renewing the bilateral agreement with Iraq. This helped increase the total amount of fuel imported from 1.5 to 2 million tons, at an annual cost of US$1.2 billion.[34] The company also managed to improve its financial situation after a substantial tariff increase in November 2022. Moreover, BDL's raising of the Sayrafa rate and the

28
Iskandar, Amine. L'eau pour sauver le Liban. IciBeyrouth. June 2022. In: https://icibeyrouth.com/liban/85078

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Hage-Boutros, Philippe. EDL sur le point de retrouver son niveau de production d'avant le black-out. L'Orient le Jour. August 2024. LIn: https://www.lorientlejour.com/article/1425057/edl-sur-le-point-de-retrouver-son-niveau-de-production-davant-le-black-out.html

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Hage-Boutros, Philippe. Ricour-Brasseur, Julien. Comment EDL gères le rationnement de son carburant. L'Orient le Jour. June 2021. In: https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.lorientlejour.com%2Farticle%2F1265231%2Fcomment-edl-gere-le-rationnement-de-son-carburant.html&psig=AOvVaw1t7pCLSoopk_BaYYQYSf6D&ust=1723197897840000&source=images&cd=vfe&opi=89978449&ved=0CBQQjhxqFwoTCKCr5caS5YcDFQAAAAAdAAAAABAQ

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L'Orient-le-Jour. EDL: les factures seront calculées au taux de Sayrafa majoré de 20%. December 2022. In: https://www.lorientlejour.com/article/1321395/edl-les-factures-seront-calculees-au-taux-de-sayrafa-majore-de-20-.html

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Libnanews. Importantes pertes financièrese pour l'EDL qui publie ses résultats pour la période 2019 à 2022. March 2024. https://libnanews.com/importantes-pertes-financierese-pour-ledl-qui-publie-ses-resultats-pour-la-periode-2019-a-2022/

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Service Économique Régional, Ambassade de France au Liban. Brève économique n°28. July 2024. In: https://www.tresor.economie.gouv.fr/Articles/8c84eaee-5dfd-4eda-8601-dbe4fe7d87b0/files/bcd7cd4a-cc22-401a-8943-1d7b8b8073de

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Sawtbeirut. Signature d'un accord avec l'Irak pour l'approvisionnement du Liban en fioul et en pétrole brut. July 2023. In: https://french.sawtbeirut.com/liban/signature-dun-accord-avec-lirak-pour-lapprovisionnement-du-liban-en-fioul-et-en-petrole-brut/

abandonment of the surcharge applied to EDL allowed the company's accounts to rebalance somewhat. The implementation of this discretionary policy had led the company to declare its intention to dollarize its tariffs to no longer depend on the central bank rates. In February 2024, the company announced it would accept payments in dollars for the first time since its establishment in 1964.[35]

At the same time, EDL managed to put its rate of non-technical losses (unpaid bills and illegal connections) on a downward trajectory. The collection of bills in the private sector has made progress, exceeding 80% across the territory, according to EDL. However, unpaid bills from institutions and public establishments between November 1, 2022, and June 30, 2023, amounted to about US$70 million.[36]

Nevertheless, in 2023, the company generated LBP542.7 billion in revenues from electricity sales, while the cost of purchased energy alone—not counting maintenance and salaries—amounted to LBP690.2 billion, suggesting that the current economic model continues to be unsustainable.[37] EDL's short-term priority is thus to secure its access to dollars and restore its finances, in order to allow it to improve its transmission and distribution network.

Increasing reliance on costly and polluting private generators

In the context of the deepening energy crisis, owners of private generators and fuel importers exploited the mismatch between electricity supply and demand, enhancing their subscription models. According to HRW,[38] experts estimate the size of the market at around US$3 billion, with diesel importers being the big winners, accounting for US$1.8 billion in 2018.[39] Generators were used for an average of three hours a day in 2010, while they have been running for nearly 20 hours since the crisis.[40]

This expansion of decentralized power systems based on diesel generators created an informal network of service providers largely impervious to government regulations and oversight[41] Although this sector is in principle illegal—violating Decree 16878/1964, which grants EDL a monopoly on the generation and sale of electricity—it has been tolerated for many decades because of EDL's chronic shortcomings. Thus, the owners of these private generators constitute a veritable cartel, grouped in the Generator Owners Syndicate, allowing them to be true 'price setters' in the absence of competition.

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Bower, Edmund. Lebanon's EDL harnesses the power of 'dollarisation'. February 2024. AGBI. In: https://www.agbi.com/analysis/economy/2024/02/lebanon-to-start-electricity-sector-dollarisation/

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L'Orient-le-Jour. Le secteur public doit 70 millions de dollars à EDL, l'Unrwa et le HCR n'ont pas les moyens de payer. November 2023. In: https://www.lorientlejour.com/article/1361575/edl-reduit-la-production-au-maximum-en-attendant-une-issue-pour-son-carburant.html

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Libnanews. Importantes pertes financièrese pour l'EDL qui publie ses résultats pour la période 2019 à 2022. March 2024. In: https://libnanews.com/importantes-pertes-financierese-pour-ledl-qui-publie-ses-resultats-pour-la-periode-2019-a-2022/

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HRW. 'Cut Off from Life Itself' Lebanon's Failure on the Right to Electricity. July 2023. In: https://www.hrw.org/sites/default/files/media_2023/03/lebanon0323web.pdf

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Ahmad, Ali. DISTRIBUTED POWER GENERATION FOR LEBANON, Market Assessment and Policy Pathways. May 2020. World Bank. In: https://documents1.worldbank.org/curated/en/353531589865018948/pdf/Distributed-Power-Generation-for-Lebanon-Market-Assessment-and-Policy-Pathways.pdf

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Najat Aoun Saliba in L'Orient-le-Jour. March 2024.

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With certain exceptions, such as Circular No. 4/1/2018, which made it mandatory to install meters for subscribers of private diesel generators. According to Ahmad Ali (2020), 60% of subscribers had installed meters by 2019, reducing their bills by half. However, challenges arose due to insufficient monitoring, lack of expertise, and resistance and manipulation of meters by generators, who saw their revenues decrease. Net-metering also increased the demand on EDL, requiring improvements, enhanced monitoring, and strengthened expertise.

While some adhere to the tariffs and directives set by the Ministry of Energy and the Ministry of Economy and Trade to try to regulate the sector since 2011, most apply fixed rates they set, sometimes in dollars. In February 2024, the price for power from private generators was officially set at LBP 34,286 per kWh[42] (about US$0.4). For comparison, the price of kWh in New York was US$0.19 in January 2024.[43] Thus, for a maximum intensity of 10A, the official monthly package for a private generator was LBP685,000 in January 2024.[44],[45] According to a 2023 Human Rights Watch report, the average Lebanese household dedicates around 44% of its monthly income to private generator subscriptions, while one out of ten households does not have access to a generator.[46] In reality, the prices set by the generator operators are often much higher, some even charging taxes to their subscribers or imposing additional fees on customers with solar panel installations.

Because of their short service life and low maintenance frequency, emissions from these generators have a negative impact on public health and environment. In her study published in 2022,[47] researcher Najat Aoun Saliba and her team estimated that emissions from generators have doubled since 2017 (where they accounted for 40% of the electrical sector's emissions).[48] The hydrocarbon materials from generator emissions are carcinogenic and cause, according to the researcher, respiratory and cardiovascular diseases. These generators are also responsible for soil and water pollution, through leaking engine oil that stagnates, percolates, and runs off in the absence of maintenance. Moreover, according to the 2023 Human Rights Watch report,[49] private generators in Lebanon, generally with a capacity of less than 500 kVA, evade regulation on pollutant emissions.

On the other hand, fuel importing companies form an oligopoly of 13 licensed oil importers, controlling two-thirds of the diesel market.[50] Their dominance stems from their substantial infrastructure —fuel shipments, storage facilities, transportation fleets, and distribution networks via petrol stations—along with backing from politicians with vested interests, and the absence of effective regulation and oversight.[51] Since the 1990s, these companies have benefited from state subsidies for fuel imports. According to an analysis by the Lebanese newspaper L'Orient Today, cited by Human Rights Watch,[52] Lebanon spent more on diesel imports for private generators in 2021 than on fuel for the national electricity company, EDL.

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L'Orient-le-Jour. Generator tariffs rise for first time in three months. February 2024. In: https://today.lorientlejour.com/article/1369876/generator-tariffs-rise-for-first-time-in-three-months.html

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https://www.electricchoice.com/electricity-prices-by-state/

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Tarifs des générateurs au Liban : le prix du kWh baisse légèrement, pour le troisième mois consécutif. Tarifs des générateurs au Liban : le prix du kWh baisse légèrement, pour le troisième mois consécutif. January 2024. In: https://www.lorientlejour.com/article/1366305/tarifs-des-generateurs-au-liban-le-prix-du-kwh-baisse-legerement-pour-le-troisieme-mois-consecutif.html#:~:text=Pour%20une%20intensité%20maximale%20de,685%20000%20livres%20(inchangé)

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The minimum wage was LBP675,000 in 2022 and LBP9 million in 2023. This rate was increased on March 20, 2024 to LBP18 million (around US$180 a month) for the private sector. In: https://libnanews.com/le-liban-augmente-le-salaire-minimum-a-18-millions-de-livres-libanaises-alors-que-les-syndicats-reclament-toujours-lequivalent-un-minimum-de-700-usd/ | In February 2024, an increase in civil servants' salaries was announced, expected to reach between US$400 and US$1,200. In: https://icibey-routh.com/economie/319349

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HRW. 'Cut Off from Life Itself' Lebanon's Failure on the Right to Electricity. July 2023. In: https://www.hrw.org/sites/default/files/media_2023/03/lebanon0323web.pdf

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https://www.aub.edu.lb/articles/Pages/air-pollution.aspx

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Ahmad Ali. DISTRIBUTED POWER GENERATION FOR LEBANON, Market Assessment and Policy Pathways. May 2020. In World Bank. https://documents1.worldbank.org/curated/en/353531589865018948/pdf/Distributed-Power-Generation-for-Lebanon-Market-Assessment-and-Policy-Pathways.pdf

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HRW. 'Cut Off from Life Itself' Lebanon's Failure on the Right to Electricity. July 2023. In: https://www.hrw.org/sites/default/files/media_2023/03/lebanon0323web.pdf

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Laughlin, Shayna. Ray, Alex. Wood, David. Fuelling addiction: how importers and politicians keep Lebanon hooked on oil. The Badil. January 2022. In: https://thebadil.com/wp-content/uploads/2023/03/oil_paper_cc2023.pdf

51
Ibid.

52
HRW. 'Cut Off from Life Itself' Lebanon's Failure on the Right to Electricity. July 2023. In: https://www.hrw.org/sites/default/files/media_2023/03/lebanon0323web.pdf

Fuel importers and generator operators, whose interests are closely intertwined, benefit significantly from the status quo and possess enough power to block reforms at the highest levels of the state. This was demonstrated in 2018 for example, when generator operators caused a widespread electricity outage in response to the Ministry of Energy's attempt to enforce the installation of meters and government-set tariffs.

Attempted reforms and ambitious initiatives fail to materialize

Decades before the crisis, attempts to reform Lebanon's energy sector, including the consideration of privatizing EDL, consistently encountered obstacles, despite the adoption of ambitious legislative measures. Law No. 462 of 2002[53] aimed to unbundle the power sector by breaking the monopoly held by EDL over the generation, transmission, and distribution of electricity, and open up the electricity sector to private sector participation in distribution and generation, while ensuring independent oversight by a new independent and autonomous body, called the Electricity Regulatory Authority (ERA). In particular, the law mandates the ERA issue 50-year licenses through public tenders or offerings for electricity production and distribution. However, the law has never been implemented. In the absence of the ERA, Law No. 775[54] was passed in 2006, exceptionally allowing the Council of Ministers to issue electricity production licenses based on proposals from the Minister of Energy and Water for one year, a measure extended until April 2022.

Prior to the crisis, ambitious initiatives to develop solar and wind energy projects as independent power producers were in progress, but they have all been suspended due to the crisis.[55] In May 2023, the Ministry of Energy issued permits for the establishment of 11 photovoltaic solar parks, each with a capacity of 15 MW, representing an investment of 10 to 15 million dollars per project, spread across the Bekaa (3), Mount Liban (3), North Lebanon (2), and South Lebanon (3).[56] These private solar energy stations would be obligated to sell the energy they produce to EDL. Additionally, there were plans to build three more photovoltaic solar parks with a total capacity of 300 MW.

In 2019, approval was given for the erection of three wind farms in the Akkar region, adding 226 MW of capacity, in a project estimated to cost between US$300 and US$350 million.[57] Despite the interest

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Law No. 462/2002. In: مجلس النواب اللبناني | In: http://data.infopro.com.lb/file/Law%20No%20462%20Regulation%20of%20the%20Electricity%20sector.pdf

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Law No. 775/2014. In: مجلس النواب اللبناني | In: https://www.lp.gov.lb/Default

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AlJoud, Sally Abou. Experts weigh in: Why is Lebanon's solar 'boom' no longer booming? L'Orient Today. May 2024. In: https://today.lorientlejour.com/article/1413635/experts-weigh-in-why-is-lebanons-solar-boom-no-longer-booming.html

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Direction générale du Trésor. Les énergies renouvelables au Liban. April 2023. In : https://www.tresor.economie.gouv.fr/Pays/LB/les-energies-renouvelables-au-liban

shown by local and international companies, the lack of financing has halted these projects, with the exception of two licenses sold to Merit Invest this year.[58] Furthermore, these capacity additions remain insufficient to meet the current energy demand.[59]

Since 2021, and the non-renewal of the fuel supply contract with Algeria following a tainted fuel scandal in 2020,[60] EDL's production has relied exclusively on a fuel swap deal with the Iraqi government. Under this agreement, Lebanon imports heavy fuel oil from Iraq and then swaps it on international markets for types of oil suitable for its power plants. As a result, Lebanon is heavily dependent on Iraqi oil, even though it is more expensive than other options like natural gas or renewable energy sources.[61] Additionally, documents suggest that Lebanon plans to continue relying on Iraqi oil until at least 2028,[62] and to increase the volume of this agreement to boost its capacity.[63] Meanwhile, other agreements, notably with Egypt, Syria, and Jordan, remain stalled. Furthermore, Lebanon faces a shortage of liquidity to pay for the Iraqi fuel it receives, with potential costs exceeding US$5 billion by 2028,[64] thereby exacerbating the country's economic, energy, and geopolitical fragility, as evidenced by the recent power crisis in early July.[65]

II An evaluative framework of microgrid integration

The collapse of EDL in 2021 prompted a rapid increase in the deployment of solar panels, primarily in the private sector. The following is a non-exhaustive, brief overview of the opportunities for integrating microgrids, along with some of the current challenges arising from the rapid and unregulated growth of this sector.

Technical evaluation

Renewable energy potential

Lebanon holds significant potential for renewable energy sources, averaging around 300 days of sunshine per year, in addition to strong winds (an average of 30 km/h in the Akkar region), and water resources in the mountains.[66] This potential remains largely untapped, with only 7.83% of Lebanon's electricity generation coming from renewable sources in 2019,[67] including hydroelectricity[68] (which accounted for around 75% in the 1970s).[69]

58 Ibid.

59 Ibid.

60 Shawish, Hesham. Analysis: Could the tainted fuel scandal sour Lebanon-Algeria relations? BBC. May 2020. In: https://monitoring.bbc.co.uk/product/c201qhsf

61 Atallah, Nada Maucourant. Lefevre, Etienne. Lebanon plans to rely on Iraqi fuel despite unpaid bills and cheaper alternatives. The National. June 2024. In: https://www.thenationalnews.com/news/mena/2024/06/19/lebanon-plans-to-rely-on-iraqi-fuel-despite-unpaid-bills-and-cheaper-alternatives/

62 Ibid.

63 L'Orient-le-Jour. Électricité : l'Irak donne son feu vert pour approvisionner le Liban en carburant Électricité : l'Irak donne son feu vert pour approvisionner le Liban en carburant. Juillet 2024. In: https://www.lorientlejour.com/article/1419978/electricite-lirak-donne-son-feu-vert-pour-approvisionner-le-liban-en-carburant.html

64 Ibid.

65 L'Orient-le-Jour. Électricité : l'Irak donne son feu vert pour approvisionner le Liban en carburant Électricité : l'Irak donne son feu vert pour approvisionner le Liban en carburant. Juillet 2024. In: https://www.lorientlejour.com/article/1419978/electricite-lirak-donne-son-feu-vert-pour-approvisionner-le-liban-en-carburant.html

66 Direction générale du Trésor. Les énergies renouvelables au Liban. April 2023. In: https://www.tresor.economie.gouv.fr/Pays/LB/les-energies-renouvelables-au-liban

67 LCEC. The 2019 solar PV status report for Lebanon. March 2021. In: https://lcec.org.lb/sites/default/files/2021-04/LCEC1.pdf

68 Lebanon has significant potential for hydroelectric power. However, the 18 existing hydroelectric plants are outdated. Despite an installed capacity of 270 MW, actual production has plummeted to 48 MW due to the ongoing crisis. Iskandar, Amine. L'eau pour sauver le Liban. Ici Beyrouth. June 2022. In: https://icibeyrouth.com/liban/85078

69 HRW. 'Cut Off from Life Itself' Lebanon's Failure on the Right to Electricity. July 2023. In: https://www.hrw.org/sites/default/files/media_2023/03/lebanon0323web.pdf

Driven by the crisis,[70] installed solar capacity multiplied 15 times, approaching 1.5 GW in 2024.[71] Solar panel imports went from US$54 million in 2021 to US$930 million in 2022,[72] equivalent to 1,000 to 1,300 MW, or 30% of the country's needs, mainly from China.[73] In this context, mini photovoltaic grids with batteries sometimes providing up to 24/7 electricity to residents via a pre-paid card system have flourished.

However, it appears that the growth of the solar panel and battery market is slowing down. Moreover, the demand, which initially stemmed predominantly from individual projects with the onset of the 'Lebanese solar boom,' is now more likely to come from public institutions for community-based and donor-led solar projects.[74]

Network integration

In terms of technical feasibility, according to the general director and president of the Lebanese Center for Energy Conservation (LCEC) board, Pierre El Khoury,[75] 'the medium voltage network of EDL is energized all the time, so new peer-to-peer projects could connect to the medium voltage.' To achieve this, the efficiency of the grid must be improved. Investments in the network include transmission—to bring it up to standard to reduce technical losses and enable the connection of new production assets—and distribution, through the installation of smart meters, repairing the National Control Center, and upgrading high and low voltage networks. The estimated cost for these network upgrade investments could be between US$400 and US$500 million, according to Carol Ayat in her study published in 2023.[76] In its March 2024 report, the World Bank[77] suggested that critical short-term investments in the energy sector to increase low-cost supply and prepare the grid and EDL for greater integration of renewable electricity, ensuring reliability and efficiency, could reach $300 million by 2026.

Financial and economic analysis

Due to the surging demand for solar panels and batteries, the market for solar energy in Lebanon could exceed one billion dollars per year.[78] Under current market conditions, off-grid solar PV systems appear to be the cheapest deployment mode compared to diesel generators (US$0.3-0.55/kWh),[79] with a levelized cost of electricity of US$0.06/kWh[80] and US$0.2-0.25/kWh when including storage.[81] With the projected reduction in storage costs, the economics of off-grid systems will

70 RFI. Liban: la crise économique accélère la transition énergétique du pays. June 2023. In: https://www.rfi.fr/fr/moyen-orient/20230615-liban-la-crise-économique-accélère-la-transition-énergétique-du-pays

71 Direction générale du Trésor. Les énergies renouvelables au Liban. June 2024. In: https://www.tresor.economie.gouv.fr/Pays/LB/les-energies-renouvelables-au-liban

72 Ibid.

73 Direction générale du Trésor. Les énergies renouvelables au Liban. April 2023. In : https://www.tresor.economie.gouv.fr/Pays/LB/les-energies-renouvelables-au-liban

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75 Tsagas Ilias. Lebanon introduces peer-to-peer renewable energy trading. January 2024. PV Magazine. https://www.pv-magazine.com/2024/01/02/lebanon-introduces-peer-to-peer-renewable-energy-trading/

76 Ayat, Carol. RE-ENERGIZE LEBANON, 5 ACTION STEPS TO REBUILDING LEBANON'S COLLAPSED ELECTRICITY SECTOR. Issam Fares Institute for Public Policy & International Affairs. February 2023. In: https://www.aub.edu.lb/ifi/Documents/publications/research_reports/2022-2023/Re-energize%20Lebanon%20Feb%202023.pdf

77 World Bank. Lebanon country climate and development report. March 2024. In: https://www.worldbank.org/en/country/lebanon/publication/lebanon-country-climate-and-development-report

78 RFI. Liban: la crise économique accélère la transition énergétique du pays. June 2023. In: https://www.rfi.fr/fr/moyen-orient/20230615-liban-la-crise-économique-accélère-la-transition-énergétique-du-pays

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80 Ibid.

81 Direction générale du Trésor. Les énergies renouvelables au Liban. April 2023. In: https://www.tresor.economie.gouv.fr/Pays/LB/les-energies-renouvelables-au-liban

likely improve over the next few years, with projections indicating a further reduction to US$0.045/kWh by 2030 (storage not included).[82]

In his 2020 analysis, Ahmad Ali[83] estimated that for an on-grid PV solar system including storage, the net present value becomes positive at an effective rate of US$0.27 and US$0.35/kWh at discount rates of 2.25% and 8%, and with a capital cost of US$1,800/kWp for a projection in 2025. Although these projections have undoubtedly evolved in the current context, given the current levelized cost of electricity, these conditions suggest a potentially favorable economic environment for solar PV systems.

A successful integration of solar microgrids could reduce Lebanon's dependence on fossil fuel imports and improve the resilience and sustainability of its electrical grid. According to a June 2024 note from the French Treasury,[84] integrating renewable energies into the Lebanese grid necessitates a minimum baseload of 1 GW, which aligns with EDL's current installed capacity. Furthermore, the 2020 report by IRENA and the LCEC[85] suggests that a successful integration of renewable energies could allow Lebanon to reduce its dependence on fossil fuel imports, generating annual savings estimated at nearly USD 250 million, primarily through the reduction of fossil fuel imports. These savings, along with the remuneration to EDL for the right to use its distribution network, would allow the company to improve its finances before undertaking larger-scale projects. These projects will require, in the medium term, developing the grid's capacities to sustainably ensure the network's baseload.

Environmental and social impact

The implementation of solar energy systems, which emit nearly zero emissions, would significantly lessen the reliance on diesel generators. This shift promises notable environmental and public health benefits by undermining the influence of the generator and fuel importer cartels. The introduction of peer-to-peer contracts, which reward the provision of excess energy from one owner to other users, acts as a catalyst for investment in clean energy and increasingly affordable storage solutions. Additionally, it addresses the issue of energy losses caused by the 'islanding effect'—a situation where a solar PV system, in the event of a central network failure, operates independently, leading to considerable energy wastage in Lebanon due to its frequent power outages without a backup storage system.

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Olleik Ibrahim. SOLAR POWER EQUITY IN LEBANON. Arab Reform Initiative. January 2024. In: https://s3.eu-central-1.amazonaws.com/storage.arab-reform.net/ari/2024/01/09093017/2024-01-22-EN-Solar-Power-Equity-in-Lebanon.pdf

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Ahmad Ali. DISTRIBUTED POWER GENERATION FOR LEBANON, Market Assessment and Policy Pathways. May 2020. In World Bank. https://documents1.worldbank.org/curated/en/353531589865018948/pdf/Distributed-Power-Generation-for-Lebanon-Market-Assessment-and-Policy-Pathways.pdf

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Direction générale du Trésor. Les énergies renouvelables au Liban. June 2024. In: https://www.tresor.economie.gouv.fr/Pays/LB/les-energies-renouvelables-au-liban

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IRENA. LCEC. RENEWABLE ENERGY OUTLOOK – LEBANON. June 2020. In : https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jun/IRENA_Outlook_Lebanon_2020.pdf

However, an important issue which remains today is the end-of-life management of solar equipment, which is practically nonexistent in Lebanon. The National E-waste Monitor for Lebanon 2022[86] estimates that in 2021, out of 46 kt of electronic waste, only 0.09 kt were recycled. This trend is particularly concerning given the poor installation and numerous low-quality solar panels resulting from the unorganized Lebanese solar boom, which raises questions of safety and accelerates the premature obsolescence of installed panels, batteries, and inverters.[87],[88] Aside from the obvious environmental dangers, the current lack of recycling poses significant health risks, especially for disadvantaged populations most exposed to hazardous materials (mercury, lead, etc.).[89] Yet, developing a recycling plan and infrastructure represents an economic opportunity due to the valuable materials contained in solar power systems.[90]

Moreover, the energy equity index for Lebanon, as developed by the Arab Reform Initiative[91]—which evaluates a country's success in ensuring reliable and cost-effective energy access that fosters economic prosperity—highlights the extensive advantages of renewable energy, particularly solar power, for electricity consumers. These advantages include cost reductions and environmental improvements. This analysis predicts that an increase in the index from 0 to 0.38 from 2023 to 2030, reflecting the anticipated growth in solar energy use, could result in Lebanese households seeing a 77% decrease in their electricity expenses. The facilitated resale of electricity through peer-to-peer contracts also promotes a more equitable geographical—and, by extension, socio-confessional—distribution of energy, motivating households to invest in decentralized production infrastructures.

In practice, in the absence of a coherent national energy strategy, access to solar installations in Lebanon remains markedly unequal both socially and geographically. In particular, the substantial up-front costs of solar systems—approximately US$5,000[92]—along with the difficulty of obtaining government solar loans, further exacerbate these inequalities. Additionally, the limited land space in urban areas compared to rural areas for solar projects present further accessibility challenges.[93] Consequently, without adequate regulation, the Lebanese solar revolution may not only exacerbate inequalities in access to electricity, but also further undermine the very concept of collective management of energy resources as a common good.

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Ibid.

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Ibid.

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Olleik Ibrahim. Solar POWER EQUITY IN LEBANON. Arab Reform Initiative. January 2024. In: https://s3.eu-central-1.amazonaws.com/storage.arab-reform.net/ari/2024/01/09093017/2024-01-22-EN-Solar-Power-Equity-in-Lebanon.pdf

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Ibid.

Political and regulatory framework

On December 14, 2023, the Lebanese parliament enacted the landmark Law No. 318/2023[94] on decentralized renewable energy. This legislation enables authorized RE producers to distribute electricity—up to 10 MW per unit—to other parties using the EDL network, subject to a wheeling charge, the ceiling of which is determined by the ERA.[95] RE generators can also exchange electricity with EDL or store it in the grid, receiving compensation for a percentage of the remaining surplus. Additionally, the law introduces peer-to-peer electricity trading directly between parties on adjacent properties, without relying on the EDL network.

The effective implementation of Law No. 318/2023[96] and the subsequent opening of new markets hinge on the operationalization of the ERA. This independent entity is a priority as one of the primary reform requirements mandated by multilateral financial institutions for the allocation of loans. Indeed, the ERA will serve as the official authority responsible for enforcing the law and translating its provisions into actionable policies.[97] Specifically, the ERA will delineate the eligibility criteria for installing net meters, set the specifications for suitable renewable energy systems, outline the procedures and conditions for network connection, and determine the kWh price ceiling for EDL's compensation to renewable energy generators, with periodic reviews.[98]

For direct energy sales by private sector renewable energy producers, the authority will establish the necessary procedures for energy exchange and provide energy purchase contract templates, leveraging financial and technical data from producers.[99] It will also grant production licenses for IPPs, as the temporary regulation allowing the Council of Ministers to award them expired mid-2022.

This legislative advancement marks a pivotal shift, ending EDL's exclusive rights held since 1964. It leverages the crisis-driven growth of private solar panel installations and could contribute to restoring services in the energy sector in the short term and improving its financial stability in the medium term. It offers fiscal benefits to EDL through the wheeling charge and requires less investment for systemic improvements compared to large-scale projects currently on hold. Additionally, the lower costs of off-grid solar electricity generation promise considerable savings for consumers, though these will vary by project parameters. This measure enhances energy supply, security, and equity by integrating decentralized production into the central

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96
Ibid.

97
Ibid.

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Ibid.

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Ibid.

grid for more reliable distribution. It could also significantly reduce reliance on generator operators, positively impacting public health, environmental sustainability, and household economic well-being, while shifting societal attitudes toward renewable energy. Moreover, it can mitigate Lebanon's dependence on imported fuels, reinforcing state sovereignty and recalibrating the trade balance.

Finally, integrating decentralized solar energy into the EDL network opens new commercial opportunities for the private sector and could play a vital role in Lebanon's economic resurgence. The successful implementation of the law and a possible recovery from the crisis, however, is contingent upon a number of urgent reforms.

III Conclusion and recommendations

It appears that reforming the energy sector could offer a way out of the intricate and multidimensional crisis affecting Lebanon, making it an indispensable condition for any economic recovery. Although not exhaustive or sufficient on their own, the following short-term reforms could be considered by policymakers to restore the trust and transparency necessary to unlock international financing and initiate the bailout process for the sector.

- **Appoint the ERA board.** The establishment and appointment of the ERA board are essential to enable the agency to enact the necessary technical regulations to make the law operational and unlock investments for rehabilitating the network.
  a In the case of prolonged political deadlock, exceptional measures could be considered, such as temporarily appointing the ERA board of independent experts mandated by an international organization, under the supervision of national authorities. While there is currently no legal basis for such a measure, the urgency of the situation and the inability to reach consensus for over 20 years may justify the adoption of a specific law to enable this interim solution, providing the necessary guarantees to international lenders to unlock funding for critical infrastructure projects—such as transmission and distribution lines—and facilitate the integration of renewable energy sources. This approach would also help restore transparency and build trust while awaiting a final resolution on board appointments.

b It could also be considered to grant major municipalities temporary authority to issue licenses for local renewable energy projects—solar and small hydropower, in particular—and to allow renewable energy producers to sell electricity directly via local microgrids, under the supervision of the ERA. In return, financial compensation could be invested in the rehabilitation of the EDL network under the authority of the municipality. This measure would incentivize municipalities to establish effective control to reinvest in the network and energy storage systems. However, oversight by an independent body would be essential to ensure the proper allocation of funds received and to quickly address an urgent situation.

- **Enabling short-term grid upgrades to facilitate the penetration of utility scale renewables**

  a Deploy smart meters capable of precisely monitoring energy production and consumption. This measure is crucial for assessing both the technical and administrative challenges that arise with the integration of distributed solar PV systems into the EDL grid. Additionally, it will provide insights into how these challenges may change as the grid sees increased incorporation of distributed capacity. Smart meters are essential for establishing a foundation for a peer-to-peer energy exchange system, facilitating efficient and direct transactions between energy producers and consumers. However, the rollout of these smart meters and the subsequent operationalization of this innovative energy exchange model are contingent upon the formal establishment of the ERA.

  b Implement a pricing system that accurately reflects production, management, and infrastructure costs. The deployment of smart net metering systems is expected to facilitate the integration of self-generated electricity into the grid, enabling the implementation of dynamic tariffs that adapt to real-time variations in production and grid management costs. Such tariffs should not only reflect the actual cost per kilowatt-hour produced by EDL, but also cover expenses for grid maintenance, balancing services, and reserves, which are essential for managing the intermittency of renewable energy. To ensure financial stability and attract continued investment, these tariffs must be regularly adjusted to reflect evolving cost structures and consumption patterns. This requires strong regulatory oversight and real-time data monitoring.

b Regulate and integrate private generators. Previous reforms failed, in part, by not considering key stakeholders like private generator owners. Integrating diesel generators into hybrid models should focus on encouraging operators to adopt solar PV systems, as Law No. 318/2023 opens opportunities for new revenue streams through peer-to-peer trading and wheeling, while also reducing operational costs associated with diesel consumption. Financial support, such as tax relief, along with technical assistance on integration challenges like overcurrent protection and reactive power compensation, should be provided. Effective oversight is essential to ensure proper use of incentives. Additionally, other incentive-based mechanisms, such as carbon penalties or taxes on diesel-only generators, could accelerate the phase-out of diesel and encourage cleaner energy adoption.

- **Establishing a comprehensive national strategy across the renewable energy value chain** is essential for bridging the geographical and social disparities resulting from private and localized micro-grid initiatives. This strategic approach should also facilitate the anticipation and securing of current and future energy needs.

  a Creation of a robust regulatory framework is essential to ensure compliance and safety in the mini-grid sector, which has largely developed without clear standards. This framework should encompass clear technical standards for generation and distribution systems, grid interconnection, and operational requirements, including safety measures to mitigate risks such as fires, surges, and lightning. Additionally, standardized contractual agreements, like PPAs, are needed to govern relationships between micro-grid operators, consumers, and the central grid, alongside streamlined licensing procedures to encourage investment. Finally, economic regulations should be established to set retail[100] and feed-in tariffs,[101] define subsidies, and determine responsibility for interconnection costs, ensuring a transparent legal framework that secures investor confidence.

  b Support household energy consumption through social safety net programs: Consideration should be given to supporting the energy consumption of the most vulnerable households via social safety nets, including cash transfers, subsidies, or electricity prepaid cards. Concurrently, assistance for the installation of solar energy

100
The price at which electricity is sold to retail consumers by the micro-grid.

101
The price at which a micro-grid sells power to the central grid.

production systems in the most disadvantaged neighborhoods should be explored.

c Diversify supply agreements: To supplement base load amidst the intermittency of renewables, meet demand, and ensure long-term energy security, it is essential to conclude new agreements for the diversification of hydrocarbon supplies, particularly to substitute fuel for gas, which is far more cost-effective, although environmentally debatable.[102] This gas could be produced offshore or imported via a floating regasification terminal.

d Energy storage: Formulating a strategy that would allow for efficient and equitable allocation of investments, particularly in energy storage. This would mitigate the wastage of a significant portion of the produced energy,[103] thereby enhancing the reliability and efficiency of the grid.

e Develop electronic waste management and standardization. The absence of a standardization and certification system prevents authorities from controlling quality and safety along the renewable energy value chain, including the recycling of panel components. A national reflection seems necessary to address electronic waste management, particularly to establish a network for waste collection and specialized treatment plants, with the potential to process only key components domestically while commercializing complex parts via international facilities. As a short-term solution, manufacturers could be required to collect and recycle their products or to bear the associated costs. Additionally, developing technical skills along the renewable energy value chain and raising public awareness of these issues is essential.

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