

Review Article

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Energy Production and Consumption Patterns: An Examination of the State of Energy, Electricity, and Air Pollution in Lebanon

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Abstract

Natural resources including energy are very scarce in Lebanon. As such, the country imports more than 90% of the fuel to satisfy its energy and electricity needs (EIA), primarily fossil fuel based. Furthermore, fuel consumption is forecasted to grow over the next decade, exacerbating the reliance on foreign volatile energy sources. This paper provides an overview of the energy sector in Lebanon and its impact on air pollution. Similarly, population growth is expected to continue on a steady and consistent rate, while resources remain limited. To that end, electricity consumption is disproportionate to population growth, indicative of severe inefficiencies and waste. Furthermore, the total energy consumption per household in Lebanon far exceeded its counterparts in the EU and the US. The country's energy production market is severely volatile and unreliable, resulting in only a 50-70% coverage of electrical needs from public governmental sources. Consequently, current public electric generation capacity is not meeting consumption patterns, resulting in widespread power outages, blackouts, and a heavy reliance on the unregulated "mafia-like" private generation market. Furthermore, energy consumption patterns have been increasing over the past decade and are projected to continue to grow over the next 10 years. Correspondingly, emissions patterns follow a similar trend to energy consumption patterns. As a result, the World Health Organization (WHO) estimated a 100% of the population is exposed to pollution levels above the recommended guidelines. Moreover, governmental failure to regulate and protect the environment has severely impacted the country's natural resources and overall environment. As such, Lebanon was ranked 5th in the 2019 Pollution Index for Country, which examined air pollution in countries worldwide. The World Health Organization estimates the levels of air pollution in Lebanon to be at a tipping point. Furthermore, air pollution is considered the greatest threat towards the health of Lebanese citizens. The proliferation of the transportation sector, unregulated energy sector, and private diesel generators are major contributors to air pollution in the beleaguered nation. To that end, the residential sector constituted a major contributor to this pollution, accounting for more than 30% of total energy use in the country and its associated emissions. Most of this energy is provided via liquified petroleum gas (LPG) generated electricity, a major fossil fuel. This paper explores the state of energy and electricity in Lebanon and their implications on air pollution. It also examines the state of energy use within the residential sector as it relates to overall electricity and pollution patterns. Lastly, the paper provides a sampling of alternative solutions and mechanisms to combat the electricity crisis and air pollution problems.

Key Words: Energy Consumption; Electricity Generation; Residential Energy Patterns; Air Pollution

Introduction

Decades of war, political instability, and corruption have left Lebanon with severe socio-political, economical, and environmental scars. In the aftermath of the 15-year civil war, significant areas of the country including the capital Beirut laid in ruins and disarray,

during which, the environmental sector didn't fare much better. Furthermore, lack of comprehensive robust environmental policies has stamped a severe mark on the environment. Accordingly, Lebanon boasts a dismal environmental track record. Consequently, air pollution has been recognized as one of the most pressing public health issues facing the country, especially in densely populated

urban areas as Beirut (Figure 1). World Health Organization findings indicate that pollution levels in Beirut exceed all international standards. Accordingly, Lebanon is ranked 5th in the level of outdoor air pollution among 91 countries surveyed by the World Health Organization [1]. Furthermore, Beirut has been ranked as one of the most polluted cities in the world. To that end, figures released by the World Health Organization indicate that Beirut has the 176th highest level of outdoor air pollution among 1,082 cities in the world. Beirut also ranks as the 63rd most polluted city among 159 cities in the upper-middle income countries [2]. The World Health Organization based its findings on air quality metrics of cities and countries based on the annual mean concentration of particulate matter (PM10). With estimated average levels of 200µg/m³ for particulates, the potential economic, environmental, and social impacts of air pollution in Lebanon are quite grave and alarming [3].



Figure 1: Image and map showing air pollution conditions in Lebanon (Google Images)

The energy and electricity sectors were one of the hardest hit sectors in the country as a result of decades of conflict and war. The electricity sector’s infrastructure experienced severe destruction and neglect throughout the 15-year Lebanese civil war [4]. Moreover, the country’s energy infrastructure including power plants and distribution networks were decimated and severely outdated. The complete and utter dismantling of Lebanon’s public electricity infrastructure resulted in the rise of unregulated private generation, dubbed as the electricity mafia. As a result, the country experiences severe energy shortages and consistently fails to meet the demands of domestic energy needs. Accordingly, Lebanon imports more than 90% of the fuel it needs for its primary energy demand, primarily petroleum-based products. The heavy dependency on foreign fuel sources paired with unreliable and outdated energy production systems creates unsettled socio-economic and environmental conditions. As such, the energy and electricity sector, mainly thermal energy power plants, are major contributors to air pollution and greenhouse gas emissions in the country. Thermal plants are largely responsible for providing and meeting the primary electrical needs of the country. To that end, it’s estimated the building industry consumes anywhere between 45% at the low end and 75% at the high end of total electricity demand, most of which is generated in antiquated power plants utilizing petroleum fuel oil as the main source. To that end, energy generation accounts for the significant percentage of air pollutant emissions in the country (Figure 9 & 12). About half of the electricity generated is distributed to and consumed by the residential market. Consequently, the residential sector is a major contributor to air pollution, accounting for approximately 30-45% of total energy end-use consumption in Lebanon and its associated emissions [5]. This paper provides an overview of the energy and

electricity sector in Lebanon and its impact on air pollution. Fig 1

Energy Patterns

Lebanon is an energy intensive country, exceeding many neighbouring southern Mediterranean nations. Moreover, energy consumption patterns have been increasing over the past decade and are projected to continue to grow over the next 10 years [6]. This trend could be attributed to many factors, one of which is a population and an economic boom (Figure 2). The country experienced two major population booms; the first credited to the post war 1990 economic boom resulting in a large population migration back to Lebanon; the second attributed to the influx of Syrian refugees after the Syrian civil war. Accordingly, petroleum consumption patterns followed a steady trend of growth and increase in demand, triggered by the economic and population explosion (Figure 3). Moreover, petroleum consumption patterns have been predictably impacted by significant historical markers such as the post-war reconstruction, political turmoil, and Syrian civil war. Correspondingly, energy consumption patterns have followed a similar trend to petroleum consumption patterns. Nonetheless, fuel consumption and energy demand are forecasted to grow over the next 10 years. To that end, Lebanon primarily uses imported liquid petroleum gas to meet more than 90% of its primary energy needs [7].

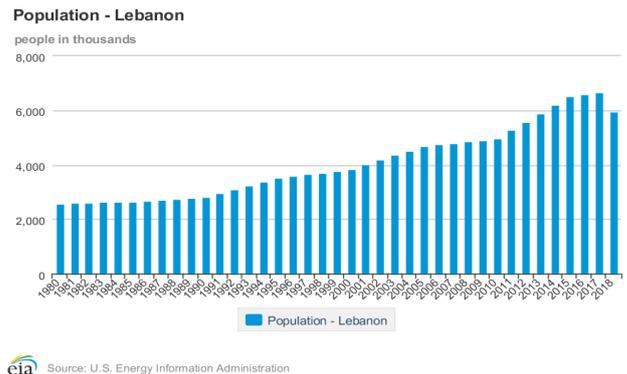


Figure 2: Population growth trends in Lebanon [7]

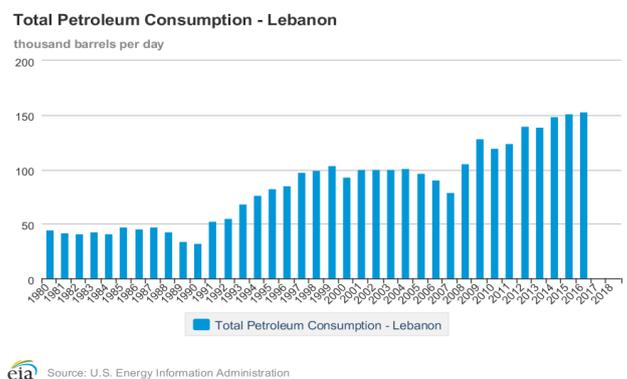
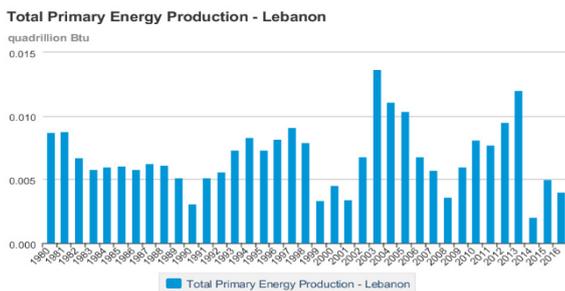


Figure 3: Petroleum consumption patterns in Lebanon [7]

Due to unreliable energy markets and a deficient infrastructure, the energy and electricity sector have failed to meet the demands of domestic energy needs. The energy production market in Lebanon is volatile and unpredictable (Figure 4), causing severe shortages in supply and inability to meet primary use needs. As a result, consumption patterns don't match production patterns (Figure 5), resulting in a heavy dependence on foreign oil imports and unstable energy markets. In 2010, the country imported 120,000 barrels per day (bbl/d) of refined oil products, accounting for over 90% (97% in 2014) of total primary energy demand in the country [5]. Similarly, energy consumption per capita follows a similar trend to petroleum and energy use patterns (Figure 6). Energy consumption patterns are heavily influenced and driven by market forces and major geo-political events.

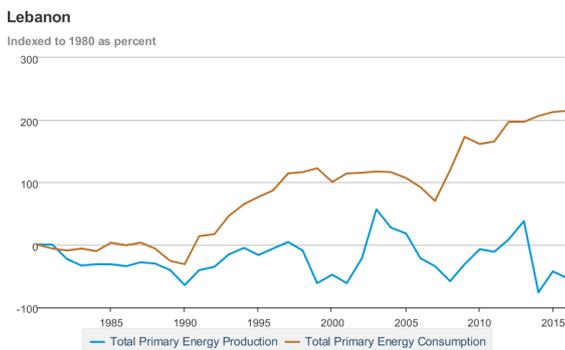
The State of Electricity

Lebanon's electricity sector has been plagued by corruption, inefficiencies, and monopolies. The crisis has pushed the country towards financial ruins. Frequent, albeit predictable, power cuts have hobbled the economy and daily lives of Lebanese citizens. Moreover, the heavily subsidized electrical sector has yielded one of the world's largest public debt burdens, amounting to \$1 billion to \$1.5 billion annually, mainly spent on fuel oil purchases [8] (Figure 7). According to International Monetary Fund (IMF), the accrued cost of subsidies totals approximately 40% of the country's total debt (2016). Furthermore, 90% of the electricity market is primarily controlled by state-owned Electricity of Lebanon (EDL), a public institution housed under the Ministry of Energy and Water (MEW) [9]. EDL is tasked with the responsibility of generating, transmitting, and distributing electrical energy in the whole of Lebanon. However, EDL is not able to satisfy consumption needs (13,200 GWh in 2006) as it frequently experiences severe shortages in generating capacity, yielding only a 60% coverage. As a result, private and self-generation markets are estimated to represent around 30-40% of all electrical generation [10]. Thus, Lebanese consumers pay two electrical bills, one for EDL and the other for private operators, usually twice the public electrical bill. Accordingly, Lebanese pay the highest electric bills in the region, while experiencing the lowest quality service.



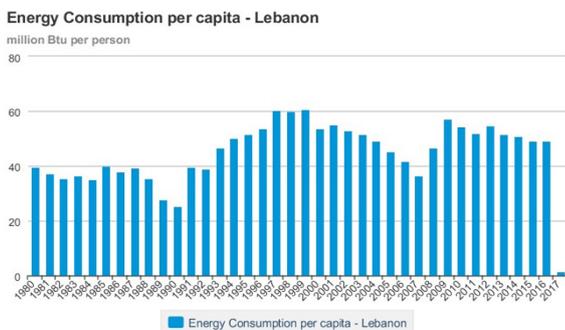
Source: U.S. Energy Information Administration

Figure 4: Energy production patterns in Lebanon [7]



Source: U.S. Energy Information Administration

Figure 5: Primary energy production and consumption patterns in Lebanon [7]



Source: U.S. Energy Information Administration

Figure 6: Energy use per capita patterns in Lebanon [7]

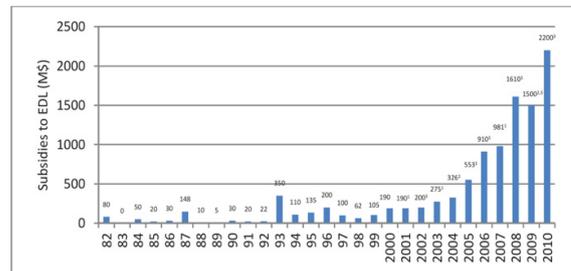


Figure 7: Electricity subsidies between 1982 and 2010 [18]

Aging and outdated state-owned power plants have not been able to meet 24-hour electrical consumption demands since 1975. As such, installed electrical capacity doesn't meet consumption demands, leading to substantial shortages in total electrical generation capacity (Figure 8). For approximately \$2 billion a year, Lebanon generates approximately 1,500 megawatts (MW), while domestic electricity needs are at least twice as much [11]. The country's power plants have a maximum capacity around 2,000 MW, compared to peak demands of 3,400 MW. Public sector electricity generation accounts for about 60-70% of total electrical demand, while 30-40 % is provided via private generation. Accordingly, most citizens get around 10 to 13 hours of public electricity a day, divided into 4-6 hours increments. Residents turn to neighborhood private electricity providers to augment the outstanding hours of the day. Households and businesses are heavily reliant on private generation, a primarily unregulated and unchecked industry. As such, the private generation energy market is a major player in the country's overall energy portfolio. To make things worse, the artificial cost of power billing has exacerbated the subsidies problem. Consumer public electrical cost (\$ per

KWh) has not changed since the mid 90's, even though oil prices have increased drastically. Moreover, electrical payment and billing collection is also inconsistent due to power losses through creaking transmission and siphoned power, costing EDL about half of the power its produces. As a result, public utilities neither have the installed capacity nor the monetary capability to provide the public with 24-hr electricity. To further exacerbate the issue, the sudden influx of 2 million Syrian refugees significantly overburdened the existing already overloaded power grid, resulting in severe and more frequent blackouts [11].

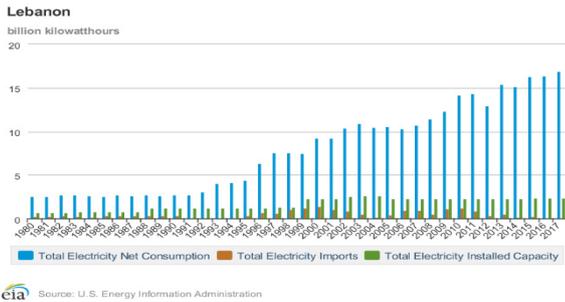


Figure 8: Electricity use and generation patterns in Lebanon [7]

The State of Air Pollution

Decades of un-regulated urban development and lack of oversight have amplified air pollution problems in Lebanon, where air pollutant levels frequently exceed international air quality guidelines and standards [12]. Electricity generation and energy production constitute the main contributors of CO2 emissions (about 40% of total emissions), followed by the transportation, industrial, and residential sectors [13] (Figure 9). Energy use trends have been increasing over the past decade and are expected to continue to propagate over the next decade. Correspondingly, carbon dioxide emission patterns follow a similar trend to energy use patterns (Figure 10). As a result, the World Health Organization (WHO) estimated a 100% of the population is exposed to pollution levels above the recommended guidelines (Figure 11). Moreover, governmental failure to regulate and protect the environment has severely impacted the country's natural resources and overall environment. As such, Lebanon was ranked 5th in the 2019 Pollution Index for Country, which examined air pollution in countries worldwide. The World Health Organization estimates the percentage of air pollution in Lebanon at 76%. Furthermore, air pollution poses the most significant threat to the health of Lebanese citizens. To that end, a two-year study of nitrogen dioxide (NO₂) in Beirut, from December 2004 to June 2006, showed an average concentration of 66µg/m³ exceeding the World Health Organization recommended annual levels of 40µg/m³ [14]. Other studies have also shown that average levels of ozone (O₃), carbon monoxide (CO), sulfur dioxide (SO₂), and particulate matter have all exceeded WHO recommended guidelines [15] (Figure 11)

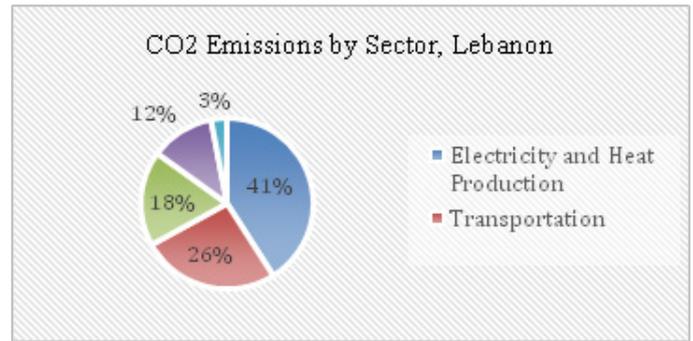


Figure 9: CO2 emissions percentage by sector [1]

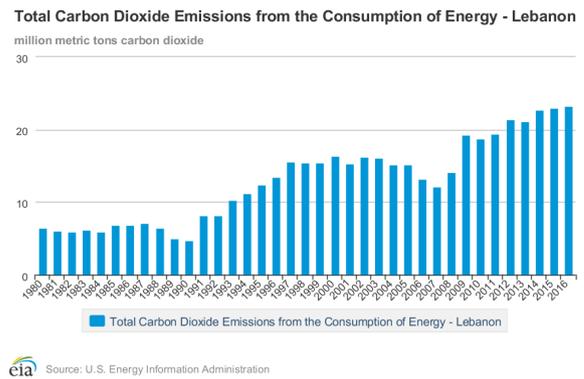


Figure 10: CO2 emissions from energy use in Lebanon [7]

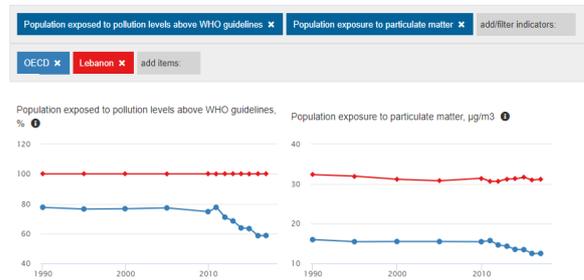


Figure 11: Percentage of Lebanese population exposed to pollution levels above WHO guidelines [16]

Air quality in Lebanon is primarily affected by anthropogenic activities. The primary sources of air pollution could be attributed to the transportation sector, energy sector, industrial sector, and construction sector (Figure 12). However, the energy sector, mainly thermal power plants (stationary source), is the one of the leading contributors to air pollution in Lebanon (Figure 9). The industry is responsible for the unrelenting black plumes that plague the capital Beirut, emitting a myriad of pollutants such as hydrocarbons, carbon monoxide, carbon dioxide, sulphur dioxide, nitrogen oxides, soot, and particulate matter [16]. Furthermore, thermal power plants are by far the most prevalent producers of carbon dioxide emissions, comprising 39% of Lebanon's total carbon dioxide emissions in 2005 (Figure 12). The impact of such plants on air quality is further amplified by the sulfur content of burning high-emission fuel such as heavy fuel oil. Most plants don't employ control equipment to mitigate emissions; their stacks aren't equipped with effective

treatment units such as flue gas desulfurization, scrubbers, filters, and dust collection units [17].

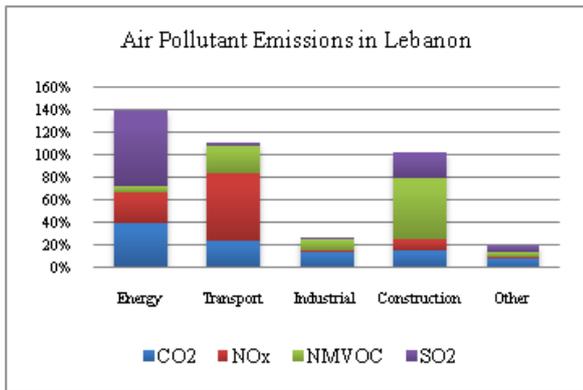


Figure 12: Contribution of economic sectors to national air pollutant emissions in Lebanon [18]

United States Agency for International Development 2012 data estimates a 229% increase in annual GHG emissions in Lebanon compared to 1990 levels, amounting to 24.34 MtCO_{2e} [20]. The energy sector constituted the predominant portion of the emissions at 21.14 MtCO_{2e}. The key driver behind this increase in GHG emissions is the growing demand for energy due to population boom, economic development, system inefficiencies, and fuel types. State-owned aging thermal plants use petroleum fuel oil, along with exhaust from diesel generators, that exacerbates air pollution and smog. Alongside the antiquated and outdated generation systems, the plants also pose a severe health risk and cost. Air pollution can cause serious respiratory diseases. Studies have shown that chronic exposure to PM has been linked with higher instances of cardiovascular problems and respiratory disorders such as lung cancer and asthma. Furthermore, researchers have been able to establish a clear connection between air pollution and various illnesses such as rheumatic and coronary heart diseases, lung and stomach cancers, and pneumonia. [19]. The World Health Organization estimated the annual cost of environmental degradation due to air pollution in Lebanon to be around 170 million dollars constituting 1.02% of GDP.

The State of Residential Sector

The residential sector in Lebanon uses approximately 30-47% of the total generated electricity, constituting the largest amount of energy end-use consumption (Figure 13). As stated before, electrical and heat generation constitute the largest portion of CO₂ and air pollutant emissions in Lebanon, including PPM, SO₂, and NO_x. Accordingly, the residential sector's substantial energy footprint is a major driver of air pollution patterns in Lebanon. Hence, it's a primary contributor to air pollution in the country. Lebanon has also seen a significant increase in energy consumption per dwelling between 2003 and 2009, due to the significant reduction of smuggled Syrian oil products after the civil war (Figure 14) [20]. Moreover, the slow proliferation of green construction methodologies within the residential sector have had a major impact on energy consumption trends as well as air pollution. This could be directly attributed to weak legislative and institutional frameworks, subsidies of energy prices, and absence

of a comprehensive national energy strategy [13]. Furthermore, lack of public awareness and educational programs have also contributed negatively to sustainable development in general. To make things worse, most green energy and sustainable construction initiatives are voluntary in nature and lack meaningful enforcement mechanisms [3]. To that end, Lebanese construction law is offering monetary incentives for voluntary thermal insulation of buildings [21]. However, the construction law does not take into consideration the environmental impacts of construction and design practices in buildings. Consequently, energy efficiency measures and upgrades aren't widely adopted due to the lack of proper legislation system with adequate monitoring agencies for enforcing and monitoring green construction practices. Moreover, lack of public awareness and absence of robust energy conservation policies have had a detrimental impact on the proliferation of green residential construction in Lebanon. Nonetheless, interest in energy performance has increased in the last few years, albeit within the commercial building sector. However, since residential structures use 47% of the total end-use energy in Lebanon [21], it's paramount to undertake a comprehensive and holistic analysis of residential energy conservation and efficiency. Nonetheless, sustainable residential construction remains primitive and severely deficient in Lebanon. Consequently, most single family detached residential buildings are not properly insulated, and in some instance, not insulated at all [21]. This is directly attributable to the fact that none of the thermal insulation standards were ever adopted and remain primarily voluntary, even though they were introduced and made public (Figure 15) [8]. Similarly, the role of governmental and public agencies in promoting sustainable development is not adequately established yet. Residential construction and development are primarily driven by aesthetics in lieu of performance. As a result, the adoption and implementation of residential sustainable construction techniques and green building upgrades have been very slow and, in some instances, non-existent. The following are few of the barriers hindering the growth of the green residential market:

- Lack of a law defining the Thermal Standards application.
- Lack of training and awareness programs for stakeholders.
- Lack of demonstration projects.
- Lack of institutional set-up and facilities for program implementation.

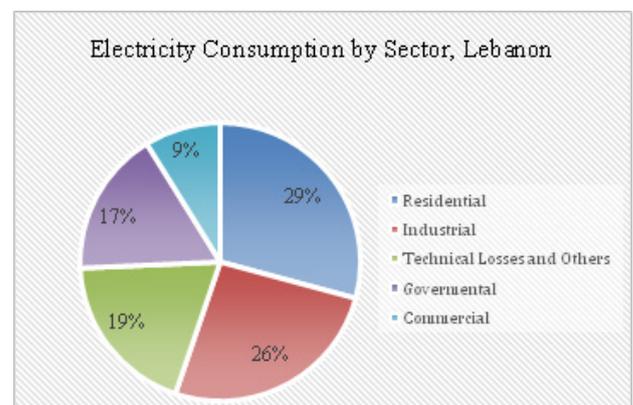


Figure 13: Electrical use per sector in Lebanon [18]

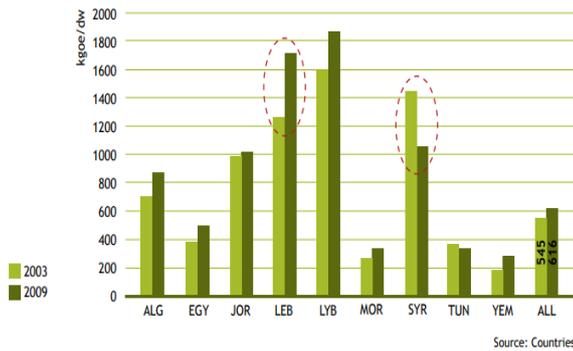


Figure 14: Energy consumption per dwelling in the Middle East region and Lebanon specifically [13]

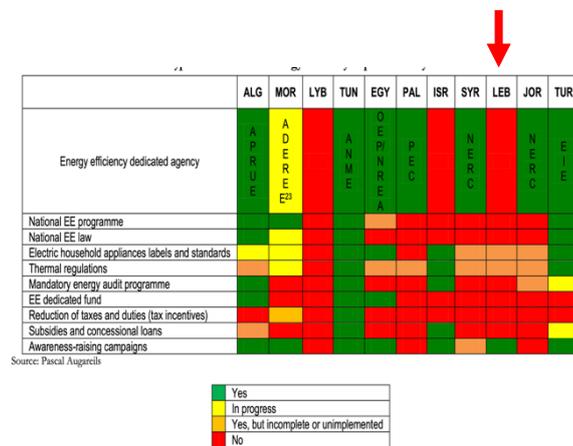


Figure 15: Types of measures for energy efficiency implemented by several Mediterranean countries [8]

Conclusions

Energy production and consumption patterns are highly susceptible to market forces and geo-political conditions. Energy consumption is also steadily increasing, while generating capacity remains deficient and unable to meet domestic energy needs. Similarly, power shortages are prevalent and widespread. The impact of an unreliable energy and electricity market has a significant effect on economic, social, and environmental conditions in Lebanon. Furthermore, antiquated fossil fuel thermal power plants paired with a primitive residential building sector have intensified environmental degradation and air pollution problems. Hence, the health and well-being of residents is at stake. Accordingly, the following steps and mechanisms are critically important to mitigate and remediate energy and air pollution problems:

- Develop and adopt enforceable legislative frameworks for residential green construction.
- Develop and adopt enforceable legislative frameworks for residential energy conservation.
- Develop and adopt enforceable legislative frameworks for monitoring sustainable initiatives.
- Develop and adopt an enforceable comprehensive national energy action plan.

- Update residential construction laws and codes to consider environmental impact of design and construction practices (performance-based approach).
- Introduce and adopt a national thermal energy standard for residential buildings.
- Offer economic incentives to adopt green building and energy saving practices.
- Promote and incentivize decentralized renewable energy technologies.
- Promote sustainable residential construction models and programs to homeowners, builders, developers, and local officials.
- Develop a sustainable residential rating system equivalent to LEED Homes.
- Raise public awareness as it relates to energy use and energy conservation measures.
- Introduce sustainable development programs and platforms in educational institutions.

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