International Journal of Mechanical and Industrial Technology ISSN 2348-7593 (Online)
Vol. 10, Issue 1, pp: (10-19), Month: April 2022 - September 2022, Available at: www.researchpublish.com

Determination of Demand-Side Management Practices affecting Energy Consumption in Egypt: Potential Benefits and Barriers

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DOI: https://doi.org/10.5281/zenodo.6985237

Published Date: 12-August-2022

***Abstract*: Over the last 30 years, the electricity and renewable energy laws in Egypt had been restructured, and the energy efficiency codes of electricity and buildings had been developed. However, there is a lack of effort towards the end user behavior and there is a need to consider energy savings that can be gained from consumption patterns' reconstruction. This paper discusses various solutions to the before mentioned matter, while discussing smart grid and demand side planning. Also, the paper explains the steps that should be followed in order to stimulate the customers to reshape their use of electricity to reach a desired alteration in the load profile.**

***Keywords*: Energy, Energy efficiency, Energy tariffs, demand side management, Energy consumption in Egypt.**

I. INTRODUCTION

1.1 Overview on energy and electricity in the world

World energy consumption is extremely influential in humanity's socio-economic-political sphere. Therefore, understanding the world energy consumption may reveal systemic trends and patterns, which could help frame current energy issues and encourage movement towards collectively useful solutions.

Figure 1 shows an energy consumption map of the whole word, the highest energy consumers are the most developed countries, such as China, USA, and Russia [1]. Despite the humongous amount of energy currently being consumed, figure 2 shows that energy consumption will continue to rise until the year 2050 [2]. Figure 3 shows that from 1950–2019 oil was the source of energy with the largest growth in consumption. The use of coal and natural gas also had considerable growth. Renewable energy grew at a rate faster than any other time in history during this period; however, still it is the least compared with other energy sources. Moreover, the demand for nuclear energy decreased, in part due to nuclear disasters [1] [2]. More recently, consumption of coal has declined relative to renewable energy [3].

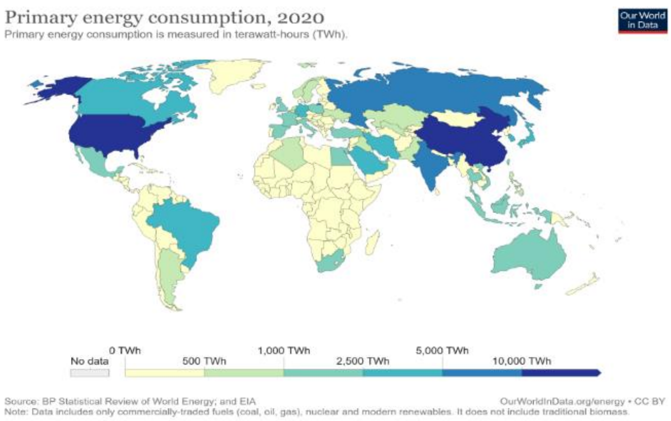


Figure 1: Primary energy consumption map, 2020 [1]

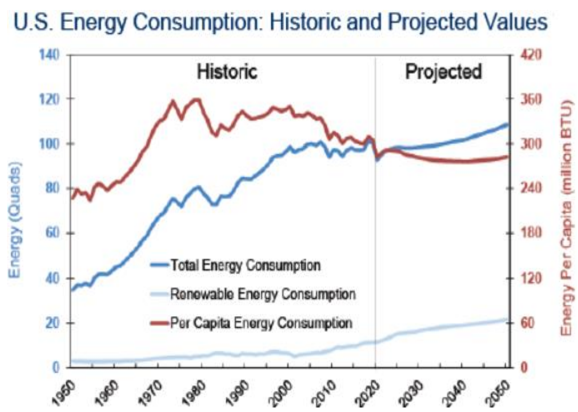
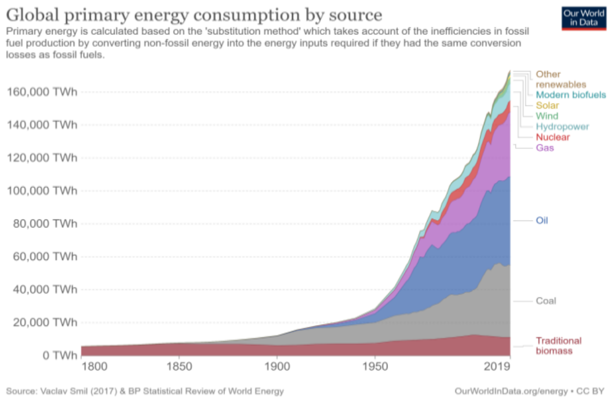


Figure 2: Historic and predicted US energy consumption [2]

As shown in figure 4, electricity generation for combustible fuels accounted for two third of the total world gross electricity production. Nuclear fuel contributed to 10.1% of world electricity production, and renewable sources accounted for 23.6% of total energy production.



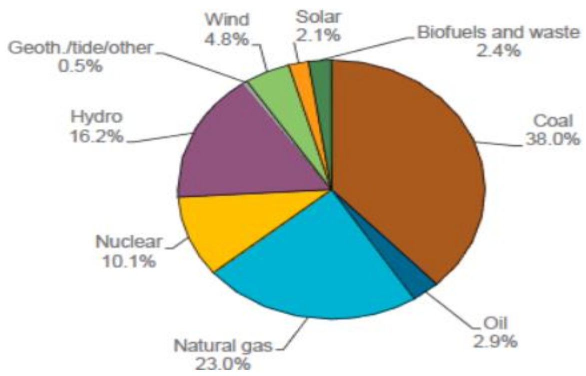


Figure 3: Global primary energy consumption by source [3] **Figure 4: World gross energy production by source, 2018 [4]**

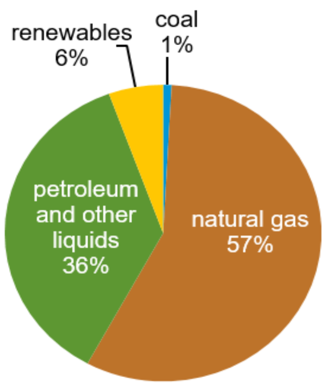
Due to the growing concerns about pollution of combustible fuels, there has been an increase in international agreements and national energy action plans to increase the use of renewable energy [4] [5]. However, from 2000–2015, oil, coal, and natural gas continued to grow at much higher rate than the renewable energy [1].

In addition, residential buildings offer an enormous energy saving potential. Besides, using energy-efficient appliances and insulation, behavioral amendments to the consumption patterns can also reduce the total amount of energy consumed. Rocky Mountain Institute in Colorado estimates that the total potential of energy savings due to efficiency improvements in the industry sector in the United States by 2050 could be as much as 30% of energy use. However, this reduction in energy consumption will need some structural policy reforms, and there is considerable debate whether these policies should have incentives or mandates.

Achieving efficient energy distribution cannot be left to the consumers' free choice, because their choices will always be affected by various barriers. Hence, it is believed that the need for managing energy consumption is mandatory.

1.2 Overview on energy and electricity in Egypt.

Egypt is the largest oil and natural gas consumer in Africa, accounting for about 22% of petroleum consumption, as well as 37% of natural gas consumption in Africa in 2016 [7]. Oil and natural gas are the primary fuels used to meet Egypt's energy needs, accounting for 93% of the country's total energy consumption in 2016 (figure 5). Energy consumption is expected to continue growing in the long term, given growth in the transportation sector, a growing population, and an improving economy [8].



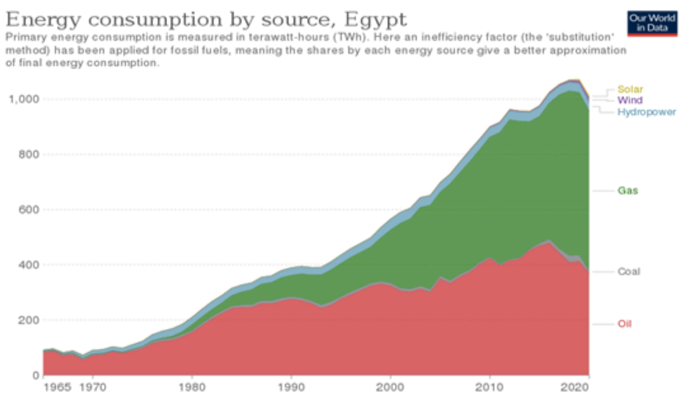


Figure 5: Energy sources in Egypt, 2020 [7] **Figure 6: Egypt's energy consumption by source [8]**

Figure 6 shows that there is a growth in the renewable energy sources. Renewable energy sources have been receiving increasing attention from Egyptian policy makers. Egypt also has plans for developing 4.3 GW of wind and solar power generation capacity. According to IHS Market [12], Egypt currently has only 30 MW of solar power generation capacity,

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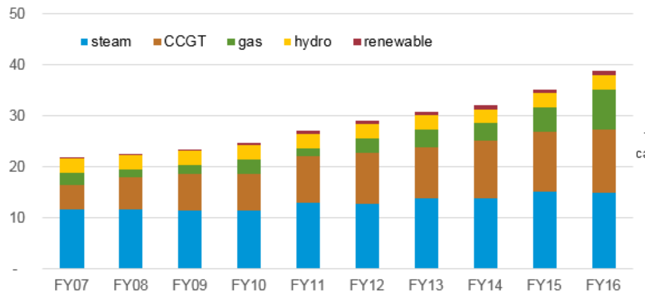
in contrast to its 1.8 GW of solar energy capacity. The Egyptian government also declared the commencement of its program for nuclear power plants for electricity production in 2007 [9]. Despite all these efforts, renewable energy sources are still incomparable to oil and gas sources.

Conventional thermal generation accounted for approximately 90% of generation capacity in Egypt, and natural gas-fired generation accounted for approximately 75% of total generation output. Given the development of natural gas projects in the country, natural gas-fired generation is expected to remain the dominant fuel source for generation, as shown in figures 7 and 8 [10].



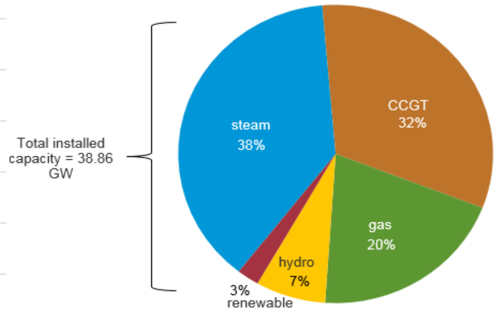


Figure 7: Installed capacity in the electricity grid by source, 2016 [10] **Figure 8: installed capacity in the electricity grid by source [10]**

Before the founding of the Egyptian Electricity Holding Company (EEHC) in 2000, the Egyptian power system was not operated unscathed. However, since the early 2000s, power outage rates and durations, as well as distribution system losses, have trended downwards. The Egyptian power system is now significantly more able to avoid power shortages during annual peak demand periods [11]. Figure 9 summarizes the Egyptian government efforts towards rationing energy consumption. Over the period of 2017 – 2020 energy use per capita was decreasing, as it reached a figure which is less than 10 MWh for the first time since 2007.

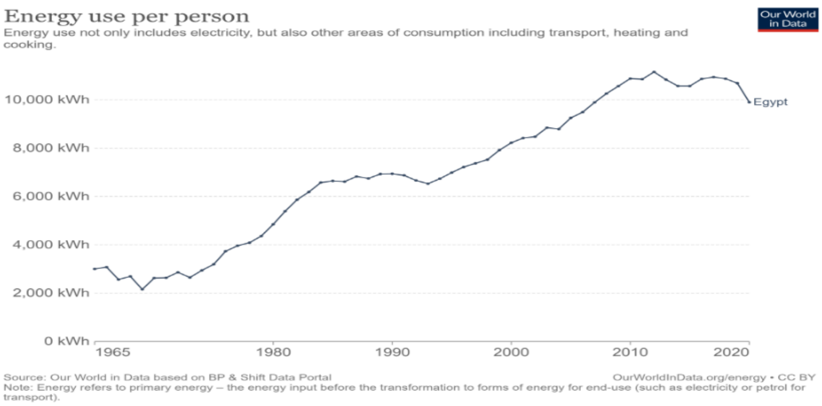
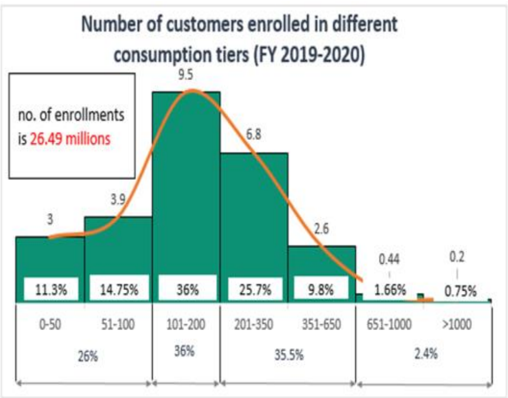


Figure 9: Egypt's energy use per person



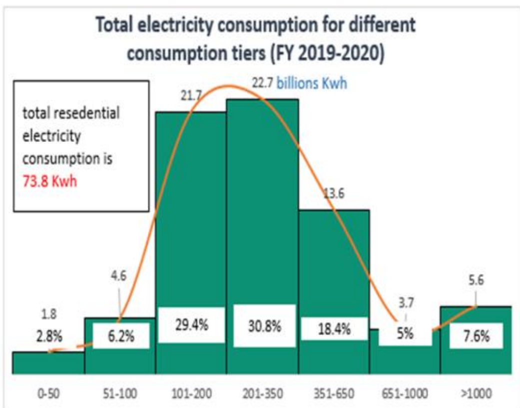


Figure 10: Number of customers enrolled in different consumption Tiers of residential electricity consumption, FY 2019-2020 [25] **Figure 11: Total electricity consumption for different consumption tiers, FY 2019-2020 [25]**

Figures 10 and 11 show data about the number of customers and their consumption, presented by the EEHC official release for fiscal year 2019 - 2020. They present that 25.7% of consumers are demanding 30.8% of the total domestic energy consumption, and that 2.41% of all the consumers, demand 12.6% of the total energy produced [25]. Hence, the inefficiency in the allocation of electricity should be targeted in order to ration the consumption.

II. EFFICIENCY OF ENERGY CONSUMPTION INEGYPT

Figure 12 represents the distribution of electricity consumption among different sectors [25]. It shows that the residential and government buildings and urban structure in Egypt consume the largest portion of total electricity generated.

Sector	Consumption Percentage
Residential	42.10%
Industrial	27.90%
Governmental Institutions	5.60%
Commercial Market	5.50%
Facilities & Sanitation	4.30%
Agriculture	4.30%
Public Lighting	3.10%
Others (offices, clinics, petrol stations, etc.)	7.20%

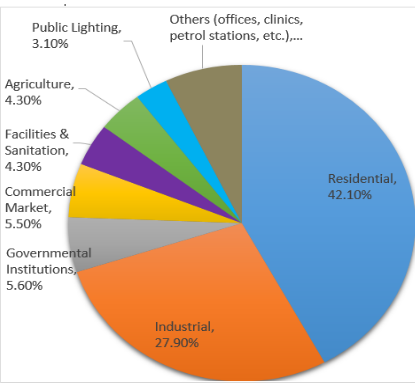


Figure 12: Electricity consumption in Egypt by sector, FY 2018-2019 [25]

Moreover, energy costs are highly subsidized in Egypt. In July 2014 the Egyptian government introduced a range of subsidy reforms through increases in official prices of energy in order to significantly reduce the energy subsidies. Table 1 shows that the amount of subsidy levied by the government decreases at an increasing rate as the consumption increases, this data was acquired from EEHC 2019 – 2020 press release figures [19].

Table 1: The value of electricity consumption and the government subsidies for different levels of consumption [25]

Electricity Tariff for FY 2019-2020			
Average Monthly Consumption	**Total Value (EGP/Month)**	**Paid by Resident (EGP/Month)**	**Government Subsidy (EGP/Month)**
50	57.1	16.0	41.1
100	114.2	37.0	77.2
200	228.5	106.0	122.5
250	285.6	152.0	133.6
300	342.7	193.0	149.7
350	399.8	234.0	165.8
400	457.0	288.0	169
450	514.1	338.0	176.1
500	571.2	388.0	183.2
550	628.3	438.0	190.3
600	685.4	488.0	197.4
650	742.6	538.0	204.6
700	799.7	618.0	181.7
750	856.8	688.0	168.8
800	913.9	758.0	155.9
850	971.0	828.0	143.0
900	1028.2	898.0	130.2
950	1085.3	968.0	117.3
1000	1142.4	1038.0	104.4
1001	1143.5	1491.5	**No Subsidy**

In 2015, new electricity laws and standards had been issued to establish a fully competitive electricity market, as it had introduced several incentives to renewable energy private developers and commercial producers [12]. Therefore, what remains is to account for the end user behavior and to consider energy savings that can be gained from consumption patterns' reconstruction.

III. SMART GRID

Smart grid is a form of electricity grid which integrates a variety of operation and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficient resources. Smart grids control the production and distribution of electricity, as well as conditioning power consumption [14].

Smart grid applications enhance the communication between electricity producers and consumers, enabling the formulation of better informed decisions about how and when to produce and consume electrical power [22] [23]. Not only will this technology direct customers towards a 24/7-based demand response through economic incentives for continuous control of the load, but also the possibility of load shedding will diminish due to the distribution of the load.

One of the strengths of the application of smart grid is time-based pricing. Therefore, customers can limit their consumption during peak load times [25]. Smart grid application encourages demand response by providing real time data to suppliers and consumers, but the economic and environmental incentives remain the driving force behind the practice.

To reduce (flatten) the peak loads, communications and metering technologies signal smart devices when energy demand is high and track how much electricity is used and when it is used. It also enables electricity providers to reduce consumption by communicating to devices directly in order to prevent system overloads. To motivate them to cut back use and perform what is called peak load shaving; prices of electricity are changed to reflect changes in consumption.

The more the load increases, the greater the increase in the price of consumption of a unit of electricity [26]. Should the consumers and consumer devices to be aware of the high price premium for using electricity at peak load times, it is thought that consumers and businesses will tend to consume less during high demand periods. When the economic benefits of rationing down consumption at peak times are evident to businesses and consumers, they will, ideally, be more willing to include the cost of energy operation into their consumer device and building construction decisions and, hence, become more energy efficient.

Technologies are available to detect the need for load shedding, communicate the demand to participating users, automate load shedding, and verify compliance with demand-response programs. Although the amount of demand delayed may be small, the implications for the grid may be substantial, since the maximum capacity of the grid can be reduced or at least its augmentation can be delayed as peak load is now reduced. The process may involve turning down (or turning off) certain appliances or sinks. Other methods of implementing demand response approach the issue of reducing duty cycles rather than implementing thermostat setbacks [26]. Progress has been made in the field of automating demand response, yet the technologies are still under development in order to become qualified for mass usage.

IV. DEMAND SIDE PLANNING

4.1 Overview

Demand-side management is the planning, implementation, and monitoring of activities by electricity suppliers designed to influence customer to reshape their use of electricity leading to a desired alteration in the load profile [21]. In general, adjustments of demand can occur in various ways: through responding to price change signals, such as permanently different billing rates for evening and day times or exceptionally highly priced usage days. Behavioral changes can also be induced through home area networks, automated controls, or with permanent load adjustments with energy efficient appliances.

Generally, demand-side management considers the following components of energy planning: ability to influence customer use, must achieve selected objectives, ability to compete against non-demand-side management alternatives, identify how customers will respond, and the way its value is influenced by load shape [22].

4.1.1 Main elements of demand-side management

In addition, the five main elements of demand-side management planning are as following:

1. The first step is to establish overall organizational objectives, such as conserving energy resources, reducing peak demand and limiting greenhouse gas emissions.

2. The second step is to identify alternatives, which include identifying the appropriate end-uses whose peak load consumption is targeted by the predefined objectives, choosing appropriate technology alternatives and investigating market implementation methods.

3. The third step balances customer considerations, supplier considerations, and cost/benefit analysis to identify the most viable demand side management alternative(s) to pursue. Implementing the program comes as

4. The fourth step, which involves piloting the proposed alternatives until the most successful system is decided upon, which is then applied on a large scale.

5. The final step is to monitor the program in order to identify deviations.

4.1.2 Demand-side management objectives.

Demand-side management systems can have one or multiple of various objectives. Three objectives seem to be the most logical to pursue, which are peak clipping, valley filling and load shifting [26]. Peak clipping is pushing down the system's maximum load by using time-based billing rate incentives. Valley filling is the act of building off-peak loads, which is desirable when the cost of dispensing the energy is less than the cost of storing it. This is typically achieved by diverting electrical energy to energy sinks during off-peak times. Load shifting aims to flatten the load curve by moving non-imperative loads from peak times to off-peak times. This ensures a more even electricity demand.

The most important dimension in the characterization of demand-side alternatives is the selection of the appropriate market implementation methods. There are many methods for influencing customer adoption of demand-side management programs, as the following [24].

4.2 Methods influencing customer adoption of demand-side management programs

1. **Customer education:** through websites, brochures, information packets, etc.

2. **Direct customer contact:** a major advantage of this method is that it allows obtaining feedback from the consumer, thus providing an opportunity to identify and respond to major customer concerns.

3. **Trade ally cooperation:** A trade ally is defined as an organization that can influence the transactions between the supplier and its customers. If trade ally groups believe that Demand-side management programs will help them, they will likely support the program.

4. **Advertising and promotion:** Advertising uses various media to communicate a message to inform or persuade them. Promotion usually includes activities to support advertising.

5. **Alternative pricing:** Pricing as a market-influencing factor generally performs three functions: (a) transfers to consumers' information regarding the value of products being provided, (b) provides incentives to use the most efficient consumption methods, and (c) determines who can afford how much of a product. A major advantage is that the customer receives a financial incentive, but over a period of years, so that the implementer can provide the incentives as it receives the benefits.

6. **Direct incentives:** used to increase short-term market penetration of a cost control/customer option by reducing the net cash outlay required for equipment purchase or by reducing the payback period.

One of the main goals of demand side management is to be able to charge the consumer based on the true price of the utilities at that time. If consumers could be charged more during peak hours, then it will encourage the consumer to use less electricity during peak hours. A problem of DSM, though, is privacy, as consumers have to provide some information about their usage of electricity to their electricity company.

V. ENERGY TARRIFS

5.1 Overview

Energy tariff is the billing scheme that electricity suppliers debit different consumer segments for the supply of electrical energy. The tariff covers the total cost of producing and supplying electric energy, plus an additional "rationing" cost [13].

The following elements are taken into account to determine the tariff used by electricity suppliers: types of load, maximum demand, time at which load is required, power factor of the load, amount of energy used [13].

Electricity tariffs should achieve certain objectives, including – but not limited to: ability to cover the cost of generating electrical energy, recovery of the capital investment cost, recovery of the running cost of operating, and a suitable profit on the capital investment. In addition, electricity tariffs should also achieve the following characteristics: proper reasonable return, fairness, simplicity, and attractiveness [13].

Countless types of energy tariffs exist in different economies in the world. A discussion of some of these tariffs is as follows [13].

5.1.2 Types of energy tariffs

1. Flat demand rate tariff: used to Bill Street and sign lighting and the bill depends on the power rating of the appliance. Despite being easy to calculate, this tariff faces the problem of billing consumers who consume different loads alike.

2. Straight-line meter rate tariff: A fixed rate is available for per unit of energy consumed, and the tariff rate assumes direct proportionality between the amount of electrical energy consumed and the cost of consumption. However, applying this tariff implies the inability of differentiating consumers according to load factor, load diversity, and power factor.

3. Block meter rate tariff: This energy consumption is divided into blocks. The cost per unit consumed is fixed only for each block, where the cost per unit of consumption decreases as the consumer moves from one block of consumption to another. The first block has the highest cost, and it goes on decreasing accordingly, as shown in figure 13.

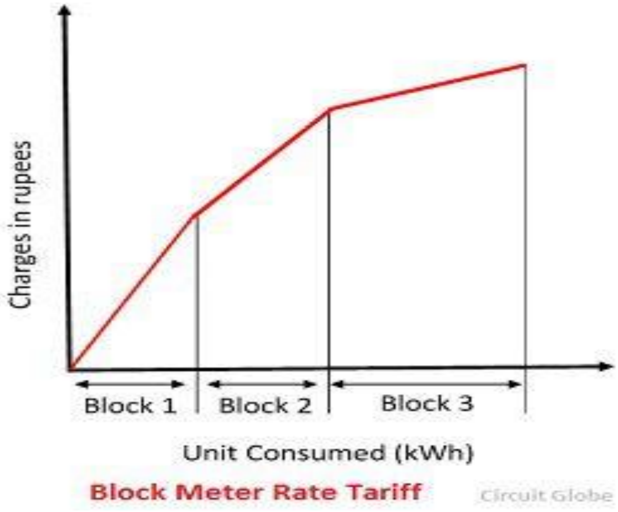


Figure 13: Block rate tariff

4. Flat-Rate tariffs: Consumers are grouped into different categories, and each type of consumers is charged at a different rate. This tariff ensures greater fairness to different types of consumers, and calculating the tariff is also simple. However, as the tariff varies with consumption, separate meters are required. This makes the application of such tariff costly and complex.

5. Two-part tariff: First part is the fixed charge, which depends on the maximum power consumed by the consumer. The second part is the running charge, which depends on the energy load consumed.

6. Power factor tariff: A low-power-factor increases the rating of the station equipment and line losses, because the demanded current increases, so a consumer having low-power-factor must be penalized.

7. Peak-load tariff: Calculates the bill based on the maximum power demand. This eliminates the disadvantage of the two-part tariff, where maximum demand is based on measured maximum power consumption.

5.2 Recommended Tariff Schemes:

Based on the previous tariff design philosophies, the following tariffs are the ones recommended for Egypt:

1. Energy rate (ER)

The energy rate tariff is composed of two parts; the first part is a fixed annual cost, and the second part is an energy cost that differs based on the individual's monthly consumption. The fixed cost is not equal for all customers. It is different for the different consumption classes according to the total amount of energy consumed. A draw-back of the Energy Rate scheme is that there is no penalty cost related to high power loads (see figure 14). The Energy Rate tariff does not differentiate between consumers who reduce their power consumption during peak times and those who do not.

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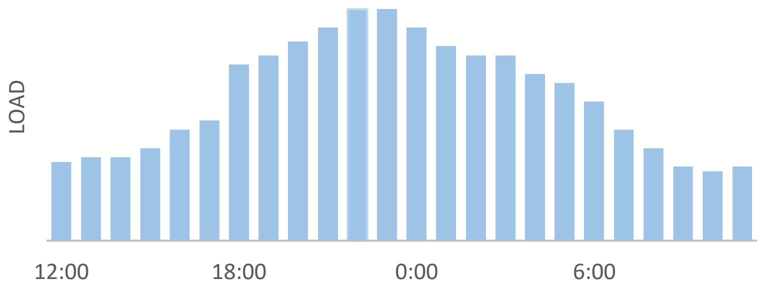
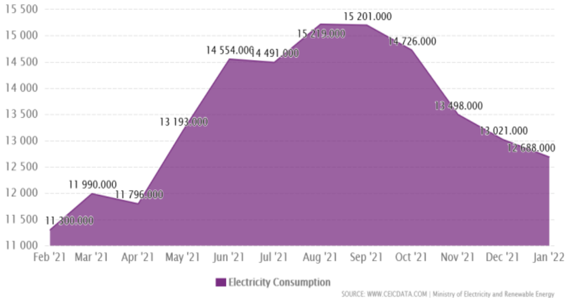


Figure 14: Illustration of the energy-based (ER) tariff scheme

2. Time-of-use (TOU)

Some hours have higher energy price than others; the hours with high pricing are the hours which historically have led to high loads. All customers will get incentive to reduce their entire load in these hours, not only the customers with the highest consumption or consumption above their limit. In Egypt, the TOU scheme is suggested to have a higher price during summer (April to Oct), because higher consumption occurs in summer as shown in figure (15), and especially during night (18:00 – 6:00) assigned as peak hours, as shown in figure (16).A drawback of this model is that the decision upon peak times will to a larger extent rely on consumption that depends on the outside temperature, which can vary largely from time to another. However, the model is intuitively easy to communicate to the customers as calculating the energy bill depends on energy (measured in kWh), and not power (measured in kW).



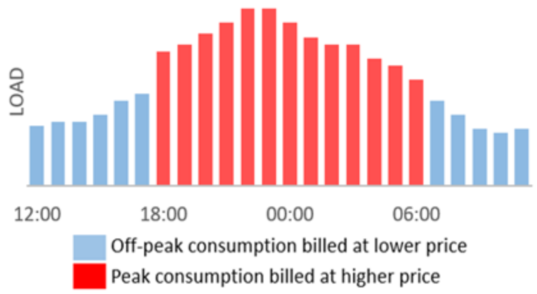


Figure 15: Egypt's electricity monthly consumption, 2021 [25] **Figure 16: Illustration of the time-of-use (TOU) tariff scheme**

3. The Measured power (MP)

Measured Power tariff scheme consists of three parts: a fixed part, an energy part and a power part. The power part is based on the highest load averaged over an hour (kWh/h) during the measuring period (see figure 17). The higher the amount of power drawn at a single instant during the day, the higher will be the bill paid by the consumer. At all other times of the day, customers will be charged for energy cost with as-low-as-possible a charge, to encourage them to consume more. Additionally, to induce them to diminish the maximum power drawn (in kW/HH/day) at a single instant. Note that there is only one hour during the measuring period, making up the power cost. A possible drawback of this model is that customers with atypical consumption patterns may be charged for large power drain even at off peak times when the grid has good capacity

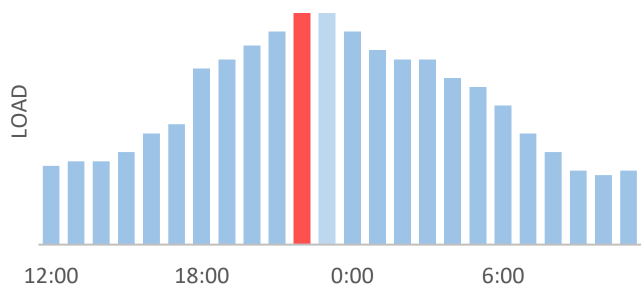


Figure 17: Illustration of the measured power (MP) tariff scheme

4. The Tiered rate (TR)

In Tiered Rate tariff, the customer pays an overuse cost if their load is above a preset limit. This tariff consists of four parts: a fixed part, a subscription part, an energy part and an overuse part. When the consumer consumes more than the subscribed limit, they will be charged for the extra consumption at a much higher rate than the units of energy consumed within the subscription limit, as shown in figure 18. As the overuse part of the tariff is accounting for all hours and loads that are above the subscription limit, one hour of overuse will not lessen the customer's economic incentive to avoid overuse at later hours. Another drawback is that if customers reduce their power drain to the subscribed limit, there is no economic incentive to reduce it further and increase energy efficiency.

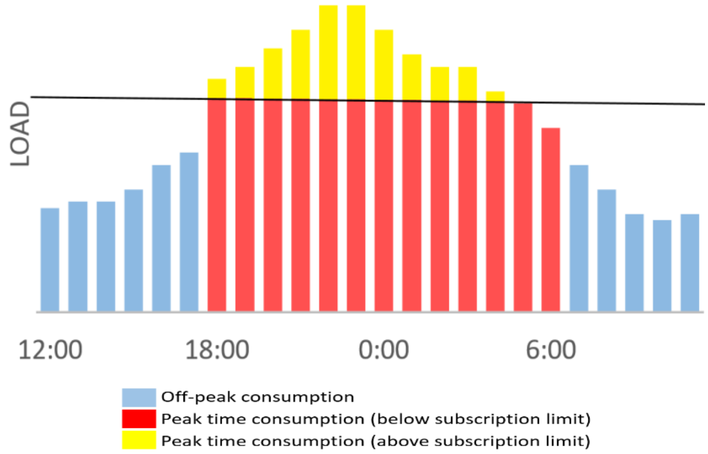


Figure 18: Illustration of the tiered rate (TR) tariff scheme

VI. CONCLUSION

During the last three decades the electricity and renewable energy laws in Egypt had been restructured, and the energy efficiency codes of electricity, buildings, and lighting had been issued. However, what remains is to account for the end user behavior and to consider energy savings that can be gained from consumption patterns' reconstruction. Thus, it is believed that Egypt is in need to develop solutions which depend on smart grid and demand side planning. The method involves the development of pricing mechanisms and contractual frameworks for residential customers to induce a demand response in the form of shifting and/or clipping their peak load.

The pricing mechanisms and contractual frameworks discussed in the paper include: a) Energy rate tariff, which calculates the energy bill based on the total amount of energy consumed, b) Time of Use tariff, which discourages customers from consuming more at certain times of the day by billing them at an increased price, c)Measured power tariff, which calculates the bill according to the maximum rate of power consumed and d) Tiered Rate tariff, in which the consumer is subscribed to a specific tier with a predetermined maximum subscription cost.

Finally, the paper recommends the use of smart grids and DSM measures to achieve peak load shaving and reduce the load on the electricity grid. This will help reduce pressure on the grid and help achieve better allocation of resources, saving government budget and avoiding opportunity cost.

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