Short-run elasticity of electricity demand in Lebanon: a focus on microgrids and solar PV systems

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Abstract

***Keywords*—**

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1 Introduction

SEB: 456 words (to "Against this...")

Lebanon has received relatively little attention in research focused on the energy transition in developing countries. However, the country faces significant challenges, particularly due to decades of political instability and the negative consequences of regional conflicts. These challenges are especially evident in the state of the publicly organized electricity grid, which has experienced near-total collapse. While the public grid was once the primary source of electricity for the population, its availability has drastically diminished. Corruption and inefficiency are frequently cited by both the local population and neutral observers as key factors behind this collapse.

As a direct consequence, municipalities and districts increasingly rely on local solutions for electricity supply, especially when they are unable or unwilling to remain without power. Due to the financial limitations of local authorities, private companies have largely assumed responsibility for electricity provision. In practice, these companies typically install diesel generators, integrating them into the grid, either through the public infrastructure or more commonly via parallel grid systems. This arrangement places generation and distribution under private control, reflecting the classic structure of microgrids as they historically developed in the United States. A microgrid, in essence, is characterized by its ability to supply local energy demands through decentralized sources within defined system boundaries.

Although Lebanon's electricity infrastructure mirrors some aspects of microgrids, particularly the reliance on local energy sources, a key distinction lies in the customer base. In Lebanon, the customers that are supplied with electricity are determined primarily by which ones provide the greatest financial benefit to private diesel generators. This selection is driven by two main factors: customers' ability to pay the established tariffs and their consumption patterns. Optimal utilization of the diesel generators depends on identifying customers with either high or consistent energy use. Those unable or unwilling to pay the tariffs, or who reduce their dependence on the microgrid by generating their own electricity through decentralized technologies like solar photovoltaic (PV) systems, risk being excluded from the microgrid.

Further complicating this situation is the fact that electricity prices within these microgrids are no longer regulated by government authorities and can be set freely by private companies. The ongoing deterioration of governance, exacerbated by regional and global tensions, has weakened the state's capacity to enforce pricing mechanisms, such as sanctions. As a result, private providers face little to no regulatory consequences, even when prices are excessively high. This raises important questions about the price elasticity of electricity demand in Lebanon's microgrids. Specifically, it remains unclear how consumers respond to price fluctuations—whether they reduce consumption by adopting energy-saving practices or by generating their own electricity through PV systems. The examination of short-run electricity demand elasticity in this context is thus essential to understanding the dynamics of Lebanon's evolving energy landscape.

Against this background, the core objective of this paper...

- Fuchs et al. [1] (How does energy modelling influence policymaking? Insights from low-and middle-income countries) + However, many models, having been developed in HICs and transferred to LMICs, are biased towards HIC contexts
- Energy models are increasingly applied in low- and middle-income countries + Context-knowledge and collaboration with local experts is crucial for relevance
- Energy systems in LMICs differ from those in HICs in several important ways; for example, levels of access to electricity, use of traditional biomass, and informal economies

2 Background

2.1 Overview of the residential electricity market in Lebanon

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2.2 Short-run elasticity of electricity demand in developing countries

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2.3 Micrograds and solar PV in delveoping countries

SEB

Shi et al. [2] the residential tariff is even lower than the production costs.

Bose and Shukla [3]: examines how sensitive are sectoral electricity consumption with respect to power failures from grids; power reliability factor; explanatory variable; regressor: defined as percentage of annual total energy shortages of power supply from utilities with respect to the total power requirement. ==¿ -0.21

Table 1
Empirical studies calculating elasticities by country.

Authors	Period	Country	Method	Short Term		Long Term	
				Price (-)	Income	Price (-)	Income
Moshiri and Santillan (2018)	2002–2012	Mexico	SURE	0.36	0.75	–	–
Labandeira et al. (2017)	–	Meta-anal.	GLS/FE	0.22–0.21	–	0.58–0.61	–
Shulte and Heindl (2017)	1993–08	Germany	QES	0.43–0.50	0.40–0.41	–	–
Wang and Mogi (2017)	1989–14	Japan	TVP	0.46–0.68	0.86–1.59	–	–
Zhang et al. (2017)	2011–12	China	FRDD	0.90	–	–	–
Miller and Alberini (2016)	1997–09	USA	Several	0.2–0.8	0.06–0.18	–	–
Sun and Ouyang (2016)	2013	China	AIDSM	0.39	0.62	–	–
Moshiri (2015)	2001–08	Iran	SUR	0.02	0.99–1.02	–	–
Agostini et al. (2014)	2006	Chile	NLS	0.38–0.40	0.11–0.12	–	–
Gomez et al. (2013)	2001–10	Spain	SARAR	0.04	0.27	–	–
Okajima and Okajima (2013)	1990–07	Japan	GMM	0.40	–	0.49	–
Zhou and Teng (2013)	2007–09	China	OLS	0.35–0.50	0.14–0.33	–	–
Arthur et al. (2012)	2002–03	Mozamb.	Deaton's	0.49–0.66	0.52–0.69	–	–
Alberini and Filippini (2011)	1995–07	USA	GMM	0.08–0.15	–	0.45–0.75	–
Filippini (2011)	2000–06	Switz.	LSDV	0.65–0.84	–	1.27–2.26	–
Halicioglu (2007)	1968–05	Turkey	ARDL	0.33	–	0.52	–
Filippini and Pachauri (2004)	1993–94	India	OLS	0.29–0.51	0.60–0.64	–	–
Nesbakken (1999)	90/93/95	Norway	C.S.	0.24–0.53	–	–	–

Notes: Labandeira et al. (2017) used a meta-analysis to identify the main factors affecting short and long-term price elasticities for different countries. He also presents an exceptional literature review on this subject.

Figure 1: Source: Estimation of elasticities for electricity demand in Brazilian households and policy implications

[4]: Literature review: Empirical literature review on price and income elasticities and policy effects

3 Material and method

Describe briefly the structure of the section

3.1 Ordinary least squares regression

We assume that the functional form of electricity demand, D_t (per time step t), follows an exponential model, consistent with established approaches in the literature. Consequently, we employ a linear double-logarithmic specification, where electricity demand serves as the dependent (endogenous) variable, while electricity price and other factors act as independent (exogenous) variables. To estimate the short-run electricity demand elasticity, we use an unlagged model as presented in Equation 1 and an ordinary least squares estimator.

$$\ln D_t = \alpha_0 + \alpha_1 \ln P_t + \alpha_2 \ln S_t + \alpha_3 \ln HDD_t + \alpha_4 \ln CDD_t + \alpha_5 \ln PG_t + \alpha_6 \ln RPV_t + \alpha_7 \ln FPV_t + \epsilon_t \quad (1)$$

Therein, P_t represents the electricity price, S_t the average number of sun hours, HDD_t the number of heating degree days, CDD_t the number of cooling degree days, PG_t the availability of the public grid (in %), RPV_t the installed capacity of rooftop (residential) solar PV systems, and FPV_t the installed capacity of solar PV farms, per time step t. ϵ_t is an error term. α_n for $n \in \{0, ..., 7\}$ are the coefficients of the independent variables, where α_1 can be directly interpreted as the elasticity of electricity demand with respect to changes in electricity price.

With respect to the form of the unlagged model in Equation 1, the following assumptions should be noted:

- The availability of the public grid (or electricity shortages from utilities) is defined as the percentage of total electricity shortage from utilities relative to the total electricity demand in each time step t (similar to the approach from Bose and Shukla [3]).
- The main reason for including the two independent variables on solar PV capacities (RPV_t and FPV_t) is the lack of data that would allow us to perform a systematic analysis of electricity demand and its substitutes. However, we argue that rooftop solar PV capacities, in particular, tend to suppress net electricity demand and should therefore be considered.
- Seasonality in electricity demand is explicitly accounted for by the heating and cooling degree days, HDD_t and CDD_t, respectively, as we do not have detailed information on electrical equipment (such as the number of air conditioners, electric heaters, etc.).

3.2 Case study

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- Name of the district: Deir Qanoun En Nahr
- 15,000 inhabitants
- 30% Industrial demand, and 70% Residential demand
- aggregated data from the whole district, which consists of three microgrids
- average diesel consumption [in L/kWh] remarkably vary because of different efficiencies of the diesel generators

- Small week diesel storage for the district: approximately 45,000 Litre
- "Governmental pricing" ==¿ recently it was an "Obligatory rate", but know it is rather a benchmark
- in the past, private companies came in trouble if prices where remarkable different ==¿ Not today anymore
- Weather data from - https://www.weatherworld.com/yearly-climate/lb/tyre.html

3.3 Data

HAYTHAM

4 Results and discussion

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Table 4
Estimated price and income elasticities.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
α_1	− 0.56***	− 0.49***	− 0.45**	− 0.45**	− 0.45**	− 0.46**	− 0.48***	− 0.50***	− 0.50***
	(0.05)	(0.15)	(0.19)	(0.19)	(0.19)	(0.19)	(0.17)	(0.18)	(0.18)
α_2	0.32***	0.26***	0.25**	0.24**	0.24**	0.20*	0.22**	0.20*	0.21*
	(0.02)	(0.09)	(0.10)	(0.10)	(0.10)	(0.11)	(0.11)	(0.11)	(0.11)
Group 1	–	–	–	–	Yes	Yes	Yes	Yes	Yes
Group 2	–	–	–	–	–	Yes	Yes	Yes	Yes
Group 3	–	–	–	–	–	–	Yes	Yes	Yes
Group 4	–	–	–	–	–	–	–	Yes	Yes
Group 5	–	–	–	–	–	–	–	–	Yes
House. FE	–	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Family FE	–	–	–	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	–	–	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	–	–	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2 Adjust.	0.33	0.46	0.49	0.49	0.49	0.48	0.51	0.51	0.51
Obs.	1585	1585	1585	1585	1585	1585	1585	1585	1585

Notes: Significance levels: * < 0.10; ** < 0.05; *** < 0.01, shown only for α_1 and α_2. Specification (1) refers to a Pooled OLS model. Specifications (2) to (9) are estimated using panel-data techniques and differ only in the controls used and/or fixed effects. Robust standard errors are in parentheses. Group 1: Household architectonic characteristics. Group 2: Electrical-equipment ownership. Group 3: Property status and kind of residence. Group 4: Household occupants' characteristics. Group 5: Social benefits. Household FE: if the same residence was observed in both periods (POF98 and POF08). Family FE: if the same family was living in the household in both periods (POF98 and POF08). Month FE: month of data collection. Year FE: year of data collection. The number of observations (Obs.) includes 627 valid observations for POF98, and 958 valid observations for POF08.

Figure 2: Source: Estimation of elasticities for electricity demand in Brazilian households and policy implications

Table 2
Parameters estimates for sectoral electricity consumption

	Electricity consumption (endogenous variable)						
	Per capita: residential	Per capita: commercial	Per capita: agricultre	Total: LT industry	Total: HT industry	Total: industry (without captive gensets)	Total: industry (with captive gensets)
Exogenous variable							
Intercept	− 0.93	− 4.78	0.76	1.14	− 2.33	0.68	− 1.40
	(1.32)ns	(− 7.04)s	(0.97)ns	(2.19)s	(− 2.57)s	(0.86)ns	(− 1.13)ns
Real per capita SDP	0.88	1.27	0.82	—	—	—	—
	(14.71)s	(24.96)s	(7.31)s				
Real total sectoral SDP	—	—	—	0.49	1.06	0.81	0.73
				(10.49)s	(15.69)s	(13.49)s	(12.20)s
Real sectoral electricity tariff	− 0.65	− 0.26	− 1.35	− 0.04	− 0.45	− 0.32	− 0.04
	(− 4.43)s	(− 2.19)s	(− 9.11)s	(− 0.23)ns	(− 2.08)s	(− 2.03)s	(− 0.22)ns
Real price of diesel oil	—	—	—	—	—	—	1.50
							(2.44)s
Number of observations	171	169	161	167	136	122	43
Adjusted R^2	0.59	0.82	0.47	0.52	0.67	0.61	0.87

Note: (1) All variables are in natural logarithms; (2) wholesale price index (WPI) data for fuel, power, light and lubricants are used as a deflator to convert the current energy prices to real price of energy; (3) figures in parentheses are estimated t-values, s denotes 'significance at 95% level of confidence', while ns denotes 'not significant'.

Figure 3: Source: Elasticities of electricity demand in India [3]

5 Conclusions

References

[1] JL Fuchs, M Tesfamichael, R Clube, and J Tomei. How does energy modelling influence policymaking? Insights from low-and middle-income countries. *Renewable and Sustainable Energy Reviews*, 203: 114726, 2024. doi: 10.1016/j.rser.2024.114726.

[2] Guoqing Shi, Xiaojian Zheng, and Fangfang Song. Estimating elasticity for residential electricity demand in China. *The Scientific World Journal*, 2012(1):395629, 2012. doi: 10.1100/2012/395629.

[3] Ranjan Kumar Bose and Megha Shukla. Elasticities of electricity demand in India. *Energy Policy*, 27(3):137–146, 1999. doi: 10.1016/S0301-4215(99)00011-7.

[4] Daniel de Abreu Pereira Uhr, André Luis Squarize Chagas, and Júlia Gallego Ziero Uhr. Estimation of elasticities for electricity demand in Brazilian households and policy implications. *Energy policy*, 129:69–79, 2019. doi: 10.1016/j.enpol.2019.01.061.