ENERGY CONSUMPTION, ENERGY POVERTY AND THE POTENTIAL OF PV SOLAR PANELS IN THE RESIDENTIAL SECTOR:

EVIDENCE FROM MOROCCO

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OUTLINE

1. Motivation
2. Objectives of the paper
3. Energy consumption in the residential sector in Morocco
4. Data
5. Determinants of energy consumption
6. Determinants of energy poverty
7. Potential of solar PV in the residential sector
8. Main conclusions

1. MOTIVATION

- In 2017, residential energy consumption accounts for almost 21% of worldwide final energy consumption in 2017, being responsible for 6% of total CO2 emissions (*IEA, 2020*).
- Energy consumption in the residential sector is expected to grow by an average of 1.4%/year from 2012 to 2040 in OECD countries, against an average increase of 2.1%/year in the same period for non OECD countries (*U.S. Energy Information Administration, 2016*).
- Energy transition in the residential sector has a significant potential to reduce greenhouses gas (GHG) emissions.
- Understanding the patterns of energy consumption at the household level is useful for policy makers to better design their energy policies.
- Few researches covering African / MENA countries (Belaid and Raoult, 2020)

2. OBJECTIVES OF THE PAPER

The objectives of this paper are threefold:

- Analyze total energy requirements at the individual household level (transportation excluded), in the Moroccan context, using national level representative survey data.
- Investigate the determinants of energy poverty, defining the latter as the households that spend more than 10% of their income in energy (Boardman, 1991)
- Investigate the economic potential of PV systems in the residential sector and discuss the implications of PV adoption in terms of government expenditures and subsidy redistribution

3. ENERGY CONSUMPTION IN THE RESIDENTIAL SECTOR IN MOROCCO

- The residential sector is the third major consumer of energy behind transport and industry.
- Energy consumption increased by 8% from 2007 to 2017.
- Butane and electricity are the main energy sources consumed by Morocco.
- From 2007 to 2017, butane consumption increased by 50% and electricity consumption by 67%, replacing solid biofuels that were the major source for cooking and heating.

3. CONTEXT: ENERGY CONSUMPTION IN THE RESIDENTIAL SECTOR IN MOROCCO

- Butane is subsidized for all households regardless of their income. In 2014, butane subsidies represent about 66% of the real cost of butane (*Ministère de l'économie, des finances et de la réforme de l'administration, 2020*).

- Electricity is subsidized for all households. The estimated amount of subsidies depends on their range of monthly consumption. The price of electricity for households consuming less than 100 kWh/month is subsidized up to 42%. This share decreases as monthly consumption increases. The electricity price of households consuming more than 500 kWh/month is subsidized up to 8% (*Verme and El-Mesnaoui, 2015*).

4. DATA

- This study is based on the the most recent Moroccan household survey published in 2018 with data from 2013-2014.
- The sample includes 15,970 households.
- The database collects household and dwelling characteristics, demographic information and annual expenditures by consumption good. In particular, energy expenditures (excluding transport) include seven types of energy sources.

4. DATA
QUALITATIVE VARIABLES

List and description of qualitative variables used in this study (categories in italic are used as a reference)

Variable	Categories	N	Frequency
Location	*Urban*	10380	0,65
	Rural	5590	0,35
Region	*North*	10167	0,64
	South	5803	0,36
Gender of the household's head	*Male*	13068	0,82
	Female	2902	0,18
Age group of the household's head	<25 years old	149	0,01
	25-45 years old	4686	0,29
	45-70 years old	9052	0,57
	> 70 years old	2083	0,13
Employment status the household's head	*Active*	11587	0,73
	Inactive	2847	0,18
	Retired	1423	0,09
	Annuitant/Other	113	0,01
Education of the household's head	*No*	11057	0,69
	Medium	977	0,06
	High	3936	0,25
Ownership of dwelling	*Owner*	11564	0,72
	Renter	2715	0,17
	Free housing	1353	0,08
	Other type of ownership	338	0,02
Type of house	Flat	1506	0,09
	Villa	275	0,02
	Modern house	8149	0,51
	Traditional house	629	0,04
	Rural house	4599	0,29
	Shantytown	646	0,04
	Other type of housing	166	0,01
Access to electricity network	*Yes*	15428	0,97
	No	542	0,03

Source: Own elaboration based on Household survey data.

4. DATA
QUANTITATIVE VARIABLES

	Unit	N	Mean	Std.Dev.	Min	Max
Total expenditures	$/y	15970	9158	7629	514	146997
Energy expenditures	$/y	15970	447	291	14	7924
Electricity expenditures	$/y	15428	239	168	0	3168
Butane expenditures	$/y	15970	146	91	0	1364
Family size	-	15970	4	2	1	6
Number of rooms	-	15970	3	2	1	15

Source: Own elaboration based on Household survey data

Descriptive data for quantitative variables

5. DETERMINANTS OF ENERGY CONSUMPTION
THE MODEL : A QUANTILE REGRESSION APPROACH

Contrarily to the OLS method which estimates the regression slope by minimizing the squared of residuals, the quantile regression estimated the regression slop by minimizing the sum of absolute residuals. Depending on the considered quantile p, the "general pth sample statistics quantile $Q(p)$ may be solved as an optimal solution to minimize the sum of asymmetrically weighted absolute error terms, with different weights for positive and negative residuals" (*Huang, 2015*) the previous that translates into:

$$\min_{\beta \in R^k} \left[\sum_{i \in \{i: y_i \geq x_i \beta\}} p|y_i - x_i'\beta| + \sum_{i \in \{i: y_i < x_i'\beta\}} (1-p)|y_i - x_i'\beta| \right]$$

5. DETERMINANTS OF ENERGY CONSUMPTION

THE RESULTS

Quantile and OLS regression coefficients

Regression results

	Dependent variable:											
	Energy expenditures				**Electricity expenditures**				**Butane expenditures**			
	Quantile regression			*OLS*	*Quantile regression*			*OLS*	*Quantile regression*			*OLS*
	25th	50th	75th		25th	50th	75th		25th	50th	75th	
LogIncome	0.236***	0.247***	0.303***	0.281***	0.292***	0.297***	0.327***	0.270***	0.208***	0.186***	0.167***	0.208***
	(0.009)	(0.009)	(0.011)	(0.008)	(0.011)	(0.011)	(0.011)	(0.013)	(0.011)	(0.010)	(0.011)	(0.009)
Family size	-0.030***	-0.035***	-0.039***	-0.035***	0.021***	0.017***	0.014***	0.019***	0.041***	0.033***	0.031***	0.039***
	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
Number of rooms	0.018***	0.018***	0.017***	0.017***	0.011***	0.012***	0.015***	0.017***	0.014***	0.015***	0.015***	0.017***
	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)
Urban	-0.025***	-0.031***	-0.055***	-0.047***	0.062***	0.059***	0.055***	0.080***	-0.035***	-0.040***	-0.038***	-0.041***
	(0.007)	(0.008)	(0.009)	(0.007)	(0.010)	(0.008)	(0.008)	(0.012)	(0.010)	(0.008)	(0.010)	(0.008)
North	0.021***	0.015***	0.015***	0.018***	0.038***	0.039***	0.042***	0.046***	0.028***	0.026***	0.018***	0.028***
	(0.004)	(0.004)	(0.005)	(0.003)	(0.005)	(0.004)	(0.005)	(0.006)	(0.005)	(0.005)	(0.005)	(0.004)
Male	-0.012*	-0.015***	-0.013*	-0.014***	-0.011	-0.012*	-0.003	-0.004	0.016**	0.025***	0.016**	0.015***
	(0.006)	(0.006)	(0.007)	(0.005)	(0.008)	(0.007)	(0.007)	(0.009)	(0.007)	(0.006)	(0.007)	(0.006)
< 25 years old	-0.115***	-0.091***	-0.067*	-0.087***	-0.122***	-0.080***	-0.083***	-0.094***	-0.215***	-0.099***	-0.050***	-0.141***
	(0.012)	(0.021)	(0.038)	(0.016)	(0.036)	(0.022)	(0.014)	(0.029)	(0.050)	(0.023)	(0.019)	(0.019)
25-45 years old	-0.020***	-0.029***	-0.033***	-0.024***	-0.050***	-0.026***	-0.032***	-0.027**	-0.007	-0.004	0.005	0.0005
	(0.007)	(0.007)	(0.009)	(0.006)	(0.009)	(0.008)	(0.009)	(0.011)	(0.009)	(0.008)	(0.008)	(0.007)
Inactive	0.020***	0.014**	0.023***	0.016***	0.022***	0.028***	0.045***	0.042***	0.009	0.026***	0.029***	0.024***
	(0.006)	(0.006)	(0.007)	(0.005)	(0.007)	(0.007)	(0.008)	(0.009)	(0.009)	(0.007)	(0.007)	(0.006)
High degree	-0.005	-0.012	-0.020**	-0.019***	0.040***	0.021**	0.004	0.030**	-0.045***	-0.055***	-0.042***	-0.048***
	(0.008)	(0.009)	(0.009)	(0.007)	(0.010)	(0.009)	(0.014)	(0.013)	(0.011)	(0.009)	(0.013)	(0.008)
Renter	-0.034***	-0.033***	-0.032***	-0.035***	-0.018***	-0.034***	-0.033***	-0.031***	-0.044***	-0.032***	-0.025***	-0.035***
	(0.005)	(0.005)	(0.006)	(0.005)	(0.006)	(0.007)	(0.007)	(0.008)	(0.007)	(0.006)	(0.007)	(0.005)
Apartment	-0.025***	-0.026***	-0.033***	-0.030***	-0.009	-0.012	-0.018**	-0.007	-0.044***	-0.059***	-0.057***	-0.058***
	(0.006)	(0.007)	(0.008)	(0.005)	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.007)	(0.008)	(0.006)
Traditional house	0.028***	0.036***	0.036***	0.035***	0.026***	0.027**	0.058***	0.036**	-0.004	0.031***	0.027**	0.017*
	(0.006)	(0.011)	(0.013)	(0.008)	(0.009)	(0.011)	(0.016)	(0.015)	(0.014)	(0.010)	(0.012)	(0.010)
Villa	0.074***	0.113***	0.085***	0.071***	0.111***	0.143***	0.125***	0.126***	-0.055***	-0.054***	-0.025	-0.055***
	(0.019)	(0.014)	(0.011)	(0.013)	(0.020)	(0.015)	(0.021)	(0.023)	(0.010)	(0.014)	(0.023)	(0.015)
Access to electricity network	0.289***	0.211***	0.100***	0.209***					0.078***	0.035***	0.006	0.046***
	(0.034)	(0.016)	(0.028)	(0.009)					(0.028)	(0.013)	(0.015)	(0.010)
Constant	1.770***	1.940***	1.937***	1.800***	1.530***	1.645***	1.635***	1.714***	1.619***	1.918***	2.166***	1.775***
	(0.051)	(0.044)	(0.055)	(0.035)	(0.053)	(0.048)	(0.052)	(0.062)	(0.058)	(0.046)	(0.050)	(0.040)
Observations	15,970	15,970	15,970	15,970	15,428	15,428	15,428	15,428	15,970	15,970	15,970	15,970
R^2				0.239				0.183				0.202
Adjusted R^2				0.238				0.182				0.201
Residual Std. Error				4.084 (df = 15945)				7.134 (df = 15404)				4.741 (df = 15945)
F Statistic				208.853*** (df = 24; 15945)				149.917*** (df = 23; 15404)				168.661*** (df = 24; 15945)

Note: *p<0.1; **p<0.05; ***p<0.01

6. DETERMINANTS OF ENERGY POVERTY
LOGIT MODEL

Following (*Ogwumike and Ozughalu, 2016*), we use a logit model to estimate the determinants of energy poverty:

$$L_i = l\,n\left(\frac{P_i}{1-P_i}\right) = \alpha_0 + \beta_i X_i (5)$$

where L_i is the logit model (natural logarithm of the odds ratio), α_0 is the constant term, β_i are the estimated coefficients and X_i the vector of predictors.

$P_i = 1$ if household is energy poor and 0 if the household is not energy poor and $(\frac{P_i}{1-P_i})$ is the odds ratio in favor of being energy poor.

6. DETERMINANTS OF ENERGY POVERTY

THE RESULTS

- Considering Boardman's threshold of expenditure in energy exceeding 10% of income (Boardman,1991), about 1 million households (5 million people) are energy poor in Morocco➔ 14% of households

- Households who are more likely to become energy poor are poor households with large family size who own houses or shantytowns in rural areas with a large number of rooms and headed by inactive men with no education

Regression results

	Dependent variable: Energy poverty	
	Coefficients	Odds ratio
Q1	3.747***	42.403
	(0.174)	
Q2	2.524***	12.482
	(0.173)	
Q3	2.008***	7.445
	(0.173)	
Q4	1.252***	3.499
	(0.180)	
Family size	0.125***	1.134
	(0.019)	
Number of rooms	0.071***	1.074
	(0.020)	
Urban	-0.770***	0.463
	(0.097)	
North	-0.012	0.988
	(0.052)	
Male	-0.141*	0.869
	(0.075)	
< 25 years old	0.011	1.011
	(0.269)	
25-45 years old	-0.080	0.923
	(0.093)	
45-70 years old	-0.069	0.934
	(0.081)	
Annuitant	0.112	1.119
	(0.320)	
Inactive	0.169**	1.184
	(0.074)	
Retired	0.033	1.034
	(0.135)	
High degree	-0.613**	0.542
	(0.270)	
Medium degree	-0.140*	0.869
	(0.074)	
Free occupation	0.087	1.091
	(0.087)	
Other occupation	-0.480**	0.619
	(0.193)	
Renter	-0.299***	0.742
	(0.089)	
Apartment	-0.340**	0.712
	(0.159)	
Other type of house	0.082	1.086
	(0.237)	
Rural house	0.285***	1.329
	(0.095)	
Shantytown	0.259**	1.295
	(0.114)	
Traditional house	0.473***	1.605
	(0.128)	
Villa	0.277	1.320
	(0.439)	
Access to electricity network	0.694***	2.002
	(0.112)	
Constant	-5.071***	0.006
	(0.263)	
Observations	15,970	
Log Likelihood	-5,294.718	
Akaike Inf. Crit.	10,645.440	
McFadden	0.2203666	
McFaddenAdj	0.2162437	
Note:	*p<0.1; **p<0.05; ***p<0.01	

Energy poverty regression results

7. THE POTENTIAL OF SOLAR PV PANELS IN THE RESIDENTIAL SECTOR

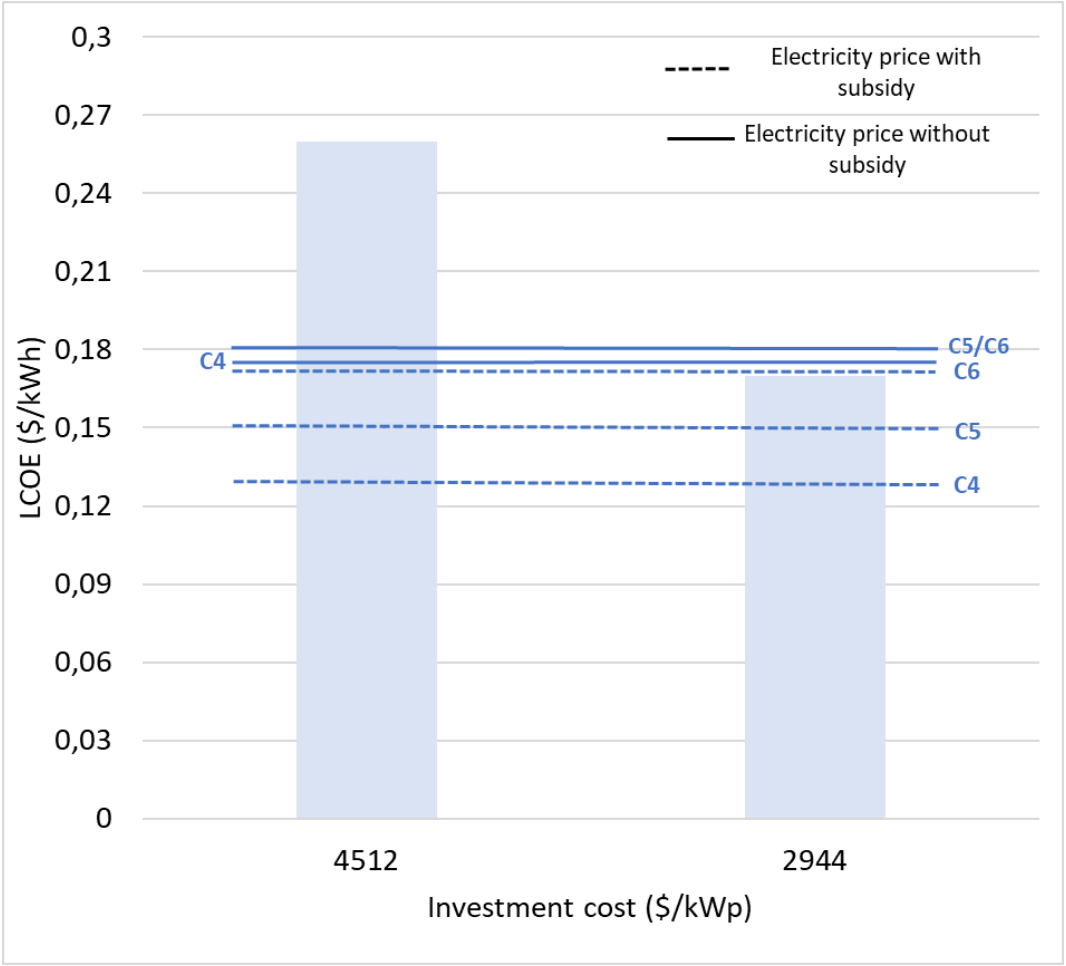
METHODOLOGY

- In order to look at the economic attractiveness of solar PV installations for Moroccan households, we use a common metric called Levelized Cost of Electricity (LCOE). The LCOE is the total lifetime costs of generation by a specific system divided by its total electricity production. Both cash and power flows have to be discounted to their present value to account for the lower worth of future consumption.
- Generally, the economic attractiveness of PV installations are based on grid parity which occurs when the LCOE is less than or equal to the price of electricity from the grid or other conventional source for each group of households.

7. THE POTENTIAL OF SOLAR PV PANELS IN THE RESIDENTIAL SECTOR

THE RESULTS

- We found that the LCOE PV is 0,17 $/kWh, suggesting that PV is attractive only for households consuming more than 500 kWh/month



Grid parity in case of subsidized and non-subsidized electricity prices

7. THE POTENTIAL OF SOLAR PV PANELS IN THE RESIDENTIAL SECTOR

THE RESULTS

- Using survey data on the distribution of electricity expenditures, we find that 8774 households consume more than 500 kWh/month.
- If all households in C6 for which PV is today competitive install solar panels, the minimum installed PV capacity in the residential sector is 19 MWp.
- Knowing that for households in C6, the unsubsidized electricity price is about 0,18 $/kWh, we can conclude that if these households for which PV is economically attractive adopt PV systems, the government would save a minimum annual amount of 526440 $.

8. MAIN CONCLUSIONS

Energy consumption

- Income and socio-demographic characteristics of households, as well as dwelling attributes are significant determinants of electricity and butane expenditures.

8. MAIN CONCLUSIONS

Energy poverty

- 14% of Moroccan households are energy poor, spending more than 10% of their expenditures to satisfy their energy needs.
- Households who are more likely to become energy poor are poor households with large family size who own houses or shantytowns in rural areas with a large number of rooms and headed by inactive men with no education.

Potential of solar PV

- Solar electricity may be attractive only for households consuming more than 500 kWh/month.
- The minimum installed PV capacity would reach 29 MWp.
- With the installation of this capacity, the government would save a minimum annual amount of 526440 $.

Thank you for your attention