Energy consumption and energy poverty in lower income countries: drivers for a solar transition

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Abstract

There is a growing interest in understanding determinants of household energy demand and energy poverty in lower-income countries. This is the case because most of the world´s increase in demand will come from the global south where there is the need to improve living standards while succeeding the energy transition. Herein we study energy demand determinants and energy poverty in Morocco and assess to which extent the adoption of PV panels could help achieve a just energy transition. We find that socioeconomic demand determinants are in line with the previous literature on developed countries but magnitudes are generally higher and some of them change signs. Moreover, inequalities drastically change demand patterns: for total energy and electricity consumption, income elasticities are higher for richer consumers, the opposite happens with butane. Regarding affordability, our main results suggest that 14% of Moroccan households are energy poor. We also find that energy poor households usually have a large family size, live in rural areas with a large number of rooms, and headed by inactive men with no education. Regarding the economic attractiveness of solar panel adoption in the residential sector as a mean to increase energy affordability and promote the energy transition, our main findings suggest that, with current subsidized prices, solar electricity is competitive for big consumers (more than 500 kWh/month). We also find that if all households for which PV is competitive actually install, the installed capacity would reach 30 MWp. With the installation of this capacity, the government would save a minimum annual amount of around half a million dollars in energy subsidies. Instead, if subsidies are dismantled for all households consuming more than 300 kWh/month, PV panels become competitive for all households that consume more than the median, liberating resources to subsidize adoption in low-income households.

Keywords : lower-middle income, Morocco, transition, energy demand, energy poverty, solar, photovoltaic, PV

JEL Classification : C2, D12, L8, Q4, O5

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1. Introduction

In the developed world, e.g. in European countries, natural gas and electricity consumption represent 36% and 25%, respectively, of total residential consumption. Instead, in developing countries in Africa, energy consumption from biofuels and waste accounted for almost 85% of total residential consumption in 2017 (IEA, 2020). According to the latest “Reference Scenario” of the International Energy Outlook 2021 (EIA, 2021a), 51% of energy consumption in OECD buildings by 2050 will come from electricity, against 55% outside the OECD (EIA, 2021b). According to (Wolfram et al., 2012), this rapid growth in non-OECD countries is due to an improvement of standards of living along with a growth of the demand for appliances and personal equipment. However, even if electricity consumption in buildings among non-OECD countries is expected to be higher than in OECD countries, household’s electricity consumption in non-OECD is expected to be on average about half the consumption of an OECD household. Disparities in energy consumption among countries correspond to the observed disparities in energy-use across households with different income levels: the higher the income, the higher the consumption of more efficient fuels such as electricity and butane. This is also known as the energy ladder phenomenon (Van der Kroon et al., 2013). According to the latest World Energy Outlook (IEA, 2022a), households in the lowest income quintile in advanced economies consume on average one third of the energy used by the highest quintile households. In developing and emerging countries, the poorest household’s consumption of modern energy is instead nine times lower than consumption of the wealthiest.

The increase in the use of electricity and butane as income increases is accepted as a trend in many countries but has been questioned (Burlig and Preonas, 2016), (Masera et al., 2000) as economic growth may not be the only driver of household energy-use. Other factors ignored in the energy ladder hypothesis such as preferences and habits, household composition and education, prices, can influence the way households consume energy. This hypothesis is supported by the “fuel stacking theory” (Nansaior et al., 2011) or “multiple fuel model” which considers that households rely on multiple fuels in their energy-use, with a mix use of different fuels. The fact of using more electricity and butane may also result in an affordability problem. As standards of living evolve in low-income countries, together with the energy transition (Dong et al., 2021) , the increasing use of these more expensive sources may lead modest households into an “energy-poverty trap”. Findings from household-level analysis may therefore serve as a basis for targeted policies in low-income countries, tailored towards specific groups (Dogan et al., 2022) aiming both at improving household’s welfare and reducing global emissions from the residential sector.

In this paper we use Morocco as a case study because it shares with most lower-income countries the energy challenges of this decade: a dynamic economy and growing living standards but with limited access to renewable energy sources and with an important deficit both in terms of energy imports and in terms of energy subsidies for the central government. Morocco reached 99.8% of rural electrification in 2021 (ONEE, 2021) and 100% in urban areas. In 2020, residential consumption in Morocco accounted for 27% of energy consumption, behind transportation (35%) and ahead of industry (19%) (IEA, 2022b). Fossil fuels, mostly butane, i.e. Liquefied Petroleum Gas (LPG)[1], is the dominant fuel with more than two thirds of total consumption, which is high compared to other countries (IEA average: 13%). It is then followed by electricity (24%) and biofuels and waste (11%). In the period 2010-2020, energy consumption in the residential sector grew by 30% (IEA, 2022b). This increase in total consumption hides opposite trends for modern fuels (especially butane and electricity) on the one side and traditional energies (biofuels and waste) on the other side. The share of butane in total energy consumption grew from 57% in 2010 to 66% in 2020. This increase can be explained by the subsidy to butane, installed in 1956 and still in place. This subsidy, which is ought to be substituted by a targeted subsidy before 2030,

[1] LPG mainly consists of butane or propane or a mix of both.

fixes butane price to a third of its market price (Verme et al., 2014). Following the same increasing trend, the share of electricity in total consumption grew from 20% in 2010 to 24% in 2020. Electricity consumption in the residential sector grew on average by 4% per year in the period 2010-2020. Contrarily to this increasing trend, the weight of biofuels and waste in total consumption decreased from 23% in 2010 to 11% in 2020 (IEA, 2022b). Electricity is also heavily subsidized for households, which together with butane subsidies, slow down the energy transition, in particular the speed of adoption of solar based technologies.

The objectives of this paper are threefold. First, we analyse household's demand for butane and electricity along the income distribution informing on better targeting policies in the verge of an inflationary crisis of fossil sources and the need for a fast energy transition in low income countries. In relation with this first objective, we constitute an extensive review of the literature showing how socioeconomic determinants of energy consumption are quite different between high and low income countries. To our knowledge, the literature on low-income countries has been growing recently but it is still limited and no empirical study has used household's surveys to explain energy demand in Morocco. Second, we study the determinants of energy poverty. Our results show which population should be targeted by focalized subsidies. Third, we investigate the economic potential of PV adoption in the residential sector and discuss the implications in terms of government expenditures and subsidy redistribution to achieve a more socially-just transition.

Our main econometric results show that income elasticity of energy consumption varies between 0,17 and 0,33, depending on the energy source considered, which is low as compared to recent studies on other countries (Gao et al., 2021). In particular, our findings suggest that living in urban areas in traditional houses and villas with a more educated household head is associated with higher electricity expenditures but lower butane expenditures. This is coherent with the limited literature on lower-middle-income countries (Belaid and Rault, 2020). As people starts using electricity and electric appliances, they substitute other forms of energy by electricity. In addition, male-headed households are associated with lower electricity expenditures but higher butane expenditures. Again, this result is in line with some of the limited studies for low-income countries (Taale and Kyeremeh, 2019) but in contrast with what is found in developed countries. This is probably due to the need for female-headed households to use efficient energy sources to save time and be able to work outside of the home.

Regarding energy poverty, our main results suggest that 14% of Moroccan households are energy poor. This is a very high number as compared to other countries and considering the fact that energy is heavily subsidized in the country. We find that households who are more likely to become energy poor are those with low income, large family size who own houses in rural areas, with a large number of rooms and headed by inactive men with no education. Results are in line with studies of energy poverty, which have mostly analyzed high-income countries, with some exceptions like e.g. house ownership. This variable may have a positive impact on energy poverty in low-income countries due to the fact that poor households own their house even if made of non-permanent materials in slums (see e.g. Taale and Kyeremeh, 2019).

Finally, we find that with the current electricity prices (which are heavily subsidized) PV is competitive only for rich households consuming more than 500 kWh/month and with a minimum installed PV capacity of about 30 MWp. Instead, if subsidies disappear panels would become competitive to all households consuming more than 300 KWh/month, i.e. all households consuming more than the Moroccan median. This finding calls for a targeted subsidy for poor households and a full stop on any other subsidy. Such policy would imply important savings for the government, be progressive in terms of income and accelerate the energy transition to cleaner sources.

The paper is organized as follows. **Section 2** reviews the literature on the determinants of household's energy consumption and energy poverty, putting in perspective the difference between lower income countries like Morocco and the rest of the literature. **Section 3** gives a description of the sources of data and displays descriptive statistics. **Section 4** discusses methodology. **Section 5** shows the results regarding the determinants of energy consumption and energy poverty, respectively and addresses the potential of PV installation for households. In the light of the previous findings, **Section 6** concludes and discusses some policy recommendations.

2. Literature review

In this section we first review the literature that analyses the determinants of energy consumption, discussing the difference between findings in high versus low income countries. We then review the thinner strand of the literature exploring energy poverty understood as a problem of affordability, which is the perspective we adopt in this paper.

In recent years, a large body of literature on the determinants of household's energy consumption has emerged, especially for electricity consumption. A comprehensive literature review of international research investigating the determinants of household's electricity demand is available in (Jones et al., 2015). Energy requirements of households are generally assessed using economic and demographic factors as well as dwelling attributes (Pachauri, 2004). Other determinants such as weather conditions, energy prices and appliances ownership are also considered when the information is available (Jones and Lomas, 2016). The determinants of energy consumption may be grouped into demand-driven factors (income, appliances, population growth, energy efficiency, weather); supply-driven factors (technical aspects including costs and prices) and public policies (taxes, subsidies).

The most widely used economic determinant is **income** for which household total expenditures is often used as a proxy. This is the case because energy expenditure is in general declared in household expenditure survey, where generally income is not available (this is the case for most African, Latin-American countries and Italy). The relationship between household income and energy consumption has been the subject of extensive research (Jones et al., 2015). (Salari and Javid, 2017) found a significant positive relationship between household electricity expenditure and income level in the USA. This result is in line with (Kaza, 2010) who found that, for the US, the influence of income on electricity use would be smaller at the lower tail of electricity distribution. Contrarily to the previous findings, (Kavousian et al., 2013) found no significant relationship between domestic electricity demand and household income in the US. (Wyatt, 2013) found that electricity consumption of the highest income group in the United Kingdom (UK) is 1.9 times higher than that of the lowest income group. In Greece, (Santamouris et al., 2007) found that electricity expenditures of high income families is 1.6 times higher than that of low income families. (Huang, 2015) found that for Taiwan income has a significant and positive effect on household electricity consumption in all quantiles, with a stronger impact in the upper quantiles than in the lower quantiles.

The positive relationship between income and energy expenditure is generally verified in the few studies considering lower-middle-income countries. (Taale and Kyeremeh, 2019) found that household income in Ghana has a significant and positive effect on electricity expenditure which indicates that wealth is an important determinant of high household electricity expenditure. (Belaid and Rault, 2020) found that household income has a significant positive impact on energy expenditure in Egypt. For developing countries, income plays a significant role in household's decision regarding fuel choices. (Mekonnen and Köhlin, 2009) investigated the determinants of household fuel choice in Ethiopia between solid fuels (fuelwood/charcoal) and non-solid fuels (electricity/ kerosene). They found that households with larger expenditures are less likely to choose only solid fuels as their main fuel. Examining the trends and patterns of household's energy consumption in Bhutan, (Rahut et al., 2016) found that household's intensity of butane and electricity consumption increases progressively across income quintiles, while it progressively decreases for firewood and kerosene across the distribution of income.

Regarding **income elasticities**, (Brounen et al., 2012) found for the Netherlands that income elasticity of demand for natural gas is about 0.06 and that the effect of income on electricity consumption is stronger than the effect upon gas for heating. Regarding electricity, they found that 1% increase in disposable income is associated with an increase of 11% of electricity usage. The majority of cross-country studies (based on household's energy consumption in developed countries) estimated income elasticities between 0.07 and 0.17 (Baker et al., 1989), (Garbacz, 1983), (Krishnamurthy and Kriström, 2013). Estimations vary strongly among countries. (Berkhout et al., 2004) others found income elasticities varying between -0.27 and 0.61 for Dutch households while (Rehdanz, 2007) found an income elasticity ranging from 0.01 to 0.1 for Germany.

Generally, in industrialized countries income elasticity of electricity demand in the residential sector is substantially lower than the one for lower-middle-income countries where the transition to modern fuels is not completely achieved. Income elasticity for energy becomes smaller as the level of income increases (Cayla et al., 2011). Exploring energy consumption in India, (Pachauri, 2004) found that expenditure's elasticity is 0.67, implying that 1% increase in per capita expenditure results in an increase of 0.67% of per capita energy requirement. (Belaid and Rault, 2020) found that income elasticity of energy expenditures ranges from 0.25 to 0.27 for Egypt.[2]

Regarding **location**, (Huang, 2015) found that urban households in Taiwan consume significantly more electricity than rural households, which is associated to the differences in income and lifestyle between urban and rural residents. Instead, (Petersen, 1982) found that households in rural areas use more electricity than those in urban areas in the state of Utah (Unites States).

For a low-middle-income country (Taale and Kyeremeh, 2019) find that households in urban areas in Ghana tend to spend more on electricity compared to their counterparts in rural areas. Investigating the determinants of energy use in Bangladesh, (Hasan and Mozumder, 2017) found also that urban households tend to consume more electricity than rural ones but the opposite is true for all other types of energy fuels excluding electricity. (Belaid and Rault, 2020) found that at the 25th quantile, households living in urban areas spend higher amount compared to those living in rural area. However, after the 25th quantile, households living in urban areas spend lower amounts in energy. The higher expenditures of rural households may be explained by the poor performance of houses in rural areas and the fact that rural households tend to live in detached houses. These results imply that the relationship between electricity demand and location is still an open question both in developed and in developing countries.

Living in different **regions** can explain the variation in energy consumption among households. Regions are used as a proxy to capture the difference in climate conditions but also on economic development (Kostakis, 2020). (Huang, 2015) found that household's electricity consumption varies across regions in Taiwan, probably due to different climatic characteristics. Using ecological zoning as a proxy for difference in climate conditions, (Taale and Kyeremeh, 2019) found that despite relatively favourable temperatures in forest and coastal zones of Ghana compared to the savannah zone, electricity consumption is higher in the two first zones than in the savannah zone. An explanation of this result may be the preponderance of commercial activities in these two ecological zones, since climate indeed interacts with economic activity. (Filippini and Pachauri, 2004) found that households living in Northern, Southern, Eastern and Western regions of India have higher electricity consumption than those living in the North-East. These variations can be explained by important differences in the overall level of development of these regions.

Family size intended as the number of members living in the household, is another determinant factor of residential energy demand. In line with (Druckman and Jackson, 2008) for the UK, (Kavousian et al., 2013) for the US and (Bedir et al., 2013) for the Netherlands, (Huang, 2015) found that the effect of

[2] A literature review on income and price elasticities with respect to different energy sources is summarized in (Kolawole et al., 2017) for a few Sub Saharan countries.

household's size is significant and positive on electricity expenditures for Taiwan. Similarly, (Zhou and Teng, 2013) found an increase of electricity consumption by 8% for every additional family member in China. (Brounen et al., 2012) found that an additional person in a Netherland household increases electricity usage by about 21% residential energy consumption whereas each additional person per household decreases per capita gas consumption by about 26%. (Leahy and Lyons, 2010) found that one persons´ household uses approximately 19% less electricity per week than a two-person household in Ireland. (Bartusch et al., 2012) found that the effect of household's size on electricity demand is insignificant for Sweden.

Contrarily to the previous findings for developed countries, in lower-middle-income countries the impact is generally the opposite. (Filippini and Pachauri, 2004) found that houses with a large number of members (greater than 6) have lower electricity consumption than those with fewer members in India. (Belaid and Rault, 2020) found that an additional household member has a decreasing impact on energy consumption and that the impact of household's size is larger on energy expenditures at the 50th quantile than at the 25th quantile of expenditures in Egypt.

Regarding the impact of family size on fuel choices, (Mekonnen and Köhlin, 2009) found that as family size increases, the likelihood of a household using solid fuels only (fuelwood/charcoal) or a mix of solid and non-solid fuels (electricity and kerosene) as the main fuel increases in Ethiopia. (Hasan and Mozumder, 2017) found that larger households in Bangladesh are associated with higher electricity consumption, but the opposite is true for all other types of energy fuels excluding electricity.

Empirical evidence of the role of **education** on household's energy consumption is still an open question both for developing and developed countries. (Hasan and Mozumder, 2017) found for the US that when household's head is educated, electricity consumption is higher than in households with non-educated heads but the opposite is true for all other types of energy fuels excluding electricity. Instead, (Salari and Javid, 2017) found that higher educational level of household's head is positively affecting savings in household gas and electricity expenditures in the US. Finally, (Bedir et al., 2013) identified no significant effect of the education level of household's head on electricity use among Dutch households.

Evidence is also mixed for low-income countries. (Huang, 2015) found that households with higher-educated heads in Taiwan consume less electricity than households with less educated heads. The effect of education is mostly significant in the 50th and 90th quantiles, indicating that an increase in education generates a greater energy saving effect in high electricity users than in low electricity users. The same findings are observed for India where households with illiterate heads have about 2% higher per capita energy requirements than literate heads (Pachauri, 2004). However, (Taale and Kyeremeh, 2019) found that households with higher years of education tend to spend more on electricity in Ghana. Similarly, regarding the impact of education on fuel choices, (Mekonnen and Köhlin, 2009) found that households with a more educated member were more likely to have non-solid fuels as their main fuel in Ethiopia. Finally, (Rahut et al., 2016), found for Bhutan that the level of education of household's head is positively associated with butane and electricity use, while it is negatively associated with kerosene and firewood, which confirms that the preference for cleaner energy increases with the level of education.

The **employment status** or economic activity of household's head has been studied with inconclusive results. (Yohanis et al., 2008) fond no significant effect of the employment status of household's head on electricity consumption in Northern Irish homes. Instead, in line with (Permana et al., 2015) for Indonesia, (Taale and Kyeremeh, 2019) found that households headed by employed people spend less on electricity compared to those headed by unemployed people in Ghana.

The effect of the **age** of household's head on energy consumption is also inconclusive both in developed and developing countries. (Brounen et al., 2012) found that elderly households consume more gas for heating than heads with other ages in the Netherlands. (Leahy and Lyons, 2010) found that households with heads aged between 45 and 64 years use significantly more electricity than those with heads aged between 35 and 44 years old in Ireland. However, they found that as the age of household heads is over 64, electricity use significantly decreases. The same conclusion is drawn in (Yohanis et al., 2008) for the UK who found that households with a head aged between 50 and 65 years old consume the largest amount of electricity whereas households with heads aged more than 65 years old use the smallest amount of electricity. (Huang, 2015) found a significant and positive relationship between electricity expenditures and the age of household's head in Taiwan.

(Pachauri, 2004) found that households headed by a person aged between 50 and 54 years old, have a 13% higher per capita energy requirement compared to households aged by a person less than 25 years old in India. Also, (Filippini and Pachauri, 2004) found that households with heads aged less than 45 years old have lower electricity consumption than households with older heads in that same country. (Belaid and Rault, 2020) found that the age of household's head has a positive effect on energy expenditure in Egypt. The effect of household's head age on energy expenditure increases from the 25^{th} quantile to the 50^{th} quantile, and decreases over the 75^{th} quantile.(Taale and Kyeremeh, 2019) found a positive but not statistically significant effect of age on electricity expenditures in Ghana. Regarding the impact of the age of household's head on fuel choices, (Mekonnen and Köhlin, 2009) found that the age of household's head is not significant in explaining the choice between non-solid fuels and a mix of solid and non-solid fuels in Ethiopia. Contrarily to the previous finding, (Rahut et al., 2016) fount for Bhutan that households with older heads tend to use mother fuels, especially LPG and electricity, compared to younger heads.

The role of the **gender** of household's head on energy demand has also been investigated in the literature but, depending on the role of women, results differ. (Huang, 2015) found for Taiwan that male-headed households consume more electricity than female-headed households but the gender effect is not obvious for high electricity users. Also for Taiwan, (Wang, 2016) established a significant inverse relationship between female household's headship and household's energy expenditure and argued that this could be explained by the fact that women are more motivated to engage in energy conservation behaviours compared to males, both to reduce energy bills and fight against greenhouse gas emissions.

In lower-middle-income countries, (Belaid and Rault, 2020) found that in male-headed households, energy expenditures are higher compared to women-headed households in Egypt. Contrarily to the previous findings, (Taale and Kyeremeh, 2019) found for Ghana that male-headed households are associated with lower expenditures on electricity compared to those headed by females. In line with the previous result, (Permana et al., 2015) found for Indonesia that electricity expenditures tend to be lower for male headed households. Regarding the impact of gender on fuel choices, (Rahut et al., 2016) for Bhutan, found that female-headed households are more likely to use LPG and electricity and less likely to use fuelwood compared to males. The use of cleaner energy sources reduces the time spent to collect firewood from the forest. These results indicate that female members may play an important role in a household's decision regarding the choice of energy for domestic use, especially for the transition from solid fuels to non-solid fuels. Contrarily to the previous finding, (Mekonnen and Köhlin, 2009) for Ethiopia found that female-headed households are more likely to choose either solid fuels only or a mix of solid and non-solid fuels as their main fuel.

Differences in household energy consumption is also explained by differences in **dwelling types**. Several studies found that electricity consumption increases as dwellings are detached one from the other. Similarly to (Bedir et al., 2013) for the Netherlands and (Wiesmann et al., 2011) for Portugal, (Brounen et al., 2012) found that households living in detached houses consume more electricity than semi-detached houses, and these consume more than apartments. (Salari and Javid, 2017) found that attached buildings consume much less energy compared to detached ones due to ability to keep energy in the US. (Curtis and Pentecost, 2015) found that detached properties are associated with higher energy expenditures compared to semi-detached houses or apartments in Ireland. Their results show that compared to households living in apartment, gas expenditures of households living in detached and semi-detached tend to be 22% and 32% higher respectively. (Leahy and Lyons, 2010) for Ireland also found that households living in apartment spend 10.7% less in electricity per week compared to those living in detached houses whereas households living in semi-detached houses tend to spend 6.9% less electricity per week compared to households living in detached houses.

The discussion is more difficult in low-income countries. (Pachauri, 2004) found that compared to those who live in flats or chawls, households living in single family houses or independent housing units have about 6% higher per capita energy requirements in India. Similarly to previous findings, (Belaid and Rault, 2020) found that households living in apartments spend 10 to 18% less in energy than households living in single housing unit in Egypt.

The role of **house ownership** in household's energy choices is inconclusive. (Huang, 2015) found a significantly and positive relationship between home ownership and electricity consumption in Taiwan. They found that owners tend to consume more electricity than renters because owners are more likely to own more electricity-consuming appliances. This result is also in line with (Wyatt, 2013) in the UK, who found that owner-occupied households have higher electricity consumption as the ownership status tend to be correlated with wealth and that rented dwellings tend to be smaller than owned ones. (Wiesmann et al., 2011) also found that households who own their own home consume significantly more electricity than those living in rented home in Portugal. However, these findings contradict the occupancy hypothesis which suggests that energy consumption of owners tend to be lower than the one of renters as owners tend to invest more in energy efficient appliances than renters (Fullerton and Wolfram, 2012). (Rehdanz, 2007) found that household's energy expenditures are significantly lower for owner-occupied dwellings in Germany.

In low-income countries (Taale and Kyeremeh, 2019) find that that homeowners in Ghana are investing little or nothing on energy-efficient appliances and practices whereas (Belaid and Rault, 2020), in line with (Rehdanz, 2007) for Germany, also found that renters spend more in energy compared to homeowners.

Regarding the **number of rooms**, (Curtis and Pentecost, 2015) for Ireland found that mid-size properties (6-10 rooms) generally spend 12% more on gas per week compared to smaller properties. However, in another study, (Bedir et al., 2013) established significant inverse relation between household electricity consumption and the number of rooms in Netherlands. (Brounen et al., 2012) found that an additional room in Dutch homes decreases electricity consumption by 0.5%. Contrarily to the previous findings, (Wiesmann et al., 2011) found that the number of rooms per dwelling in Portugal has no significant effect on electricity demand.

In line with findings by most of the previous literature, (Huang, 2015) found for Taiwan that an increase in surface is associated with higher electricity consumption. (Belaid and Rault, 2020) found that in Egypt, the number of rooms has a significant and positive effect on energy expenditures. (Taale and Kyeremeh, 2019) found also a positive and significant relationship between the number of rooms and household's electricity expenditures in Ghana, because of higher needs for lighting and cooling purposes.

Access to modern fuels and energy infrastructure including **access to electricity** itself impacts the pattern of energy use (Heltberg, 2004). (Alkon et al., 2016) found that LPG and electricity access have a positive and significant impact on energy expenditures in India. (Rahut et al., 2016) found that if households have access to electricity, they are more likely to use modern energy sources such as electricity and LPG in Bhutan. This result highlights the determinant role of the provision of clean, reliable, and cost-effective energy sources on the pattern of energy consumption in the residential sector. Indeed, modern energy sources increase expenditures and consequently they may lead to an "energy poverty trap", which we will also study herein.

All the previous findings are summarized in **Table 1.** From the previous literature review, we can conclude that literature on household's energy consumption is abundant, mainly focusing on electricity and covering mostly Europe, Asia and the USA. Studies covering Africa are negligible and mainly explore the determinants of household's energy consumption regarding fuel choices. The impacts of household's socio-economic and demographic attributes as well as of dwelling characteristics are still under debate as findings are inconclusive. Herein we contribute to this literature by focusing on a low-middle-income country in Africa: Morocco.

Table 1: Non-exhaustive summary of the effect of main energy demand drivers on energy demand

Driver	Significant (+)	Significant (-)	Not significant
Household income (effect of higher income)	**Electricity** (Huang, 2015)**, Taiwan** (Kaza, 2010)**, USA** (Taale and Kyeremeh, 2019), **Ghana** (Brounen et al., 2012), **Nehterlands** (Salari and Javid, 2017), **USA** (Wyatt, 2013), **UK** (Santamouris et al., 2007), **Greece** (Rahut et al., 2016), **Bhutan** **Gas** (Brounen et al., 2012), **Netherlands** **LPG** (Rahut et al., 2016), **Buthan** **Energy** (Belaid and Rault, 2020), **Egypt** (Rehdanz et al., 2007)[3], **Germany** (Pachauri, 2004)**, India**	**Traditional fuels** (Rahut et al., 2016), **Bhutan**	**Electricity** (Kavousian et al., 2013), **USA** **Traditional fuels** (Mekonnen and Köhlin, 2009), **Ethiopia**
Location (effect of being urban)	**Electricity** (Huang, 2015)**, Taiwan** (Taale and Kyeremeh, 2019), **Ghana** (Hasan and Mozumder, 2017), **Bangladesh**	**Electricity** (Petersen, 1982)**, USA** **Gas** (Hasan and Mozumder, 2017), **Bangladesh** **Traditional fuels** (Hasan and Mozumder, 2017), **Bangladesh**	
Region (effect of living in regions with harsh climate conditions)	**Electricity** (Huang, 2015), **Taiwan** (Kostakis, 2020), **Greece**	**Electricity** (Taale and Kyeremeh, 2019), **Ghana**	
Region (effect of living in more developed regions)	**Electricity** (Filippini and Pachauri, 2004), **India** (Taale and Kyeremeh, 2019), **Ghana**		
Family size (effect of having a large number of members)	**Electricity** (Huang, 2015)**, Taiwan** (Bedir et al., 2013), **Netherlands** (Brounen et al., 2012), **Netherlands** (Druckman and Jackson, 2008), **UK**	**Electricity** (Belaid and Rault, 2020), **Egypt** (Filippini and Pachauri, 2004), **India** (Taale and Kyeremeh, 2019), **Ghana** **Gas**	**Electricity** (Bartusch et al., 2012), **Sweden**

[3] For heating and hot water expenditures

	(Kavousian et al., 2013), **USA** (Leahy and Lyons, 2010), **Ireland** (Zhou and Teng, 2013)**, China** (Hasan and Mozumder, 2017)**, Bangladesh** **Gas** (Brounen et al., 2012), **Netherlands** **Traditional fuels** (Mekonnen and Köhlin, 2009)**, Ethiopia**	(Hasan and Mozumder, 2017), **Bangladesh** **Traditional fuels** (Hasan and Mozumder, 2017), **Bangladesh**	
Household's head education (effect of being secondary or post-secondary educated)	**Eletricity** (Taale and Kyeremeh, 2019), **Ghana** (Hasan and Mozumder, 2017)**, Bangladesh**	**Eletricity** (Huang, 2015)**, Taiwan** (Pachauri, 2004)**, India** (Salari and Javid, 2017), **USA** **Traditional fuels** (Mekonnen and Köhlin, 2009), **Ethiopia** (Rahut et al., 2016), **Bhutan**	**Eletricity** (Bedir et al., 2013), **Netherlands**
Household's head employment status (effect of being employed)		**Electricity** (Taale and Kyeremeh, 2019), **Ghana** (Permana et al., 2015), **Indonesia**	**Electricity** (Yohanis et al., 2008), **UK**
Household's head age (effect of being old / more than 65 years old)	**Electricity** (Huang, 2015)**, Taiwan** (Pachauri, 2004)**, India** (Rahut et al., 2016)**, Buthan** **Gas** (Brounen et al., 2012), **Netherlands** **LPG** (Rahut et al., 2016)**, Buthan** **Energy** (Belaid and Rault, 2020)**, Egypt**	**Electricity** (Filippini and Pachauri, 2004)**, India** (Leahy and Lyons, 2010)**, Ireland** (Yohanis et al., 2008)**, UK** **Traditional fuels** (Rahut et al., 2016)**, Bhutan**	**Electricity** (Taale and Kyeremeh, 2019), **Ghana** **Energy** (Mekonnen and Köhlin, 2009), **Ethiopia**
Household's head gender (effect of being a male)	**Electricity** (Huang, 2015), **Taiwan** (Mekonnen and Köhlin, 2009), **Ethiopia** **Energy** (Belaid and Rault, 2020), **Egypt** (Wang, 2016), **Taiwan** **Traditional fuels** (Rahut et al., 2016), **Bhutan**	**Electricity** (Taale and Kyeremeh, 2019), **Ghana** (Permana et al., 2015), **Indonesia** (Rahut et al., 2016), **Bhutan** **Traditional fuels** (Mekonnen and Köhlin, 2009), **Ethiopia** **LPG** (Rahut et al., 2016), **Bhutan**	
Dwelling type (effect of living in more detached houses)	**Electricity** Salari and Javid, 2017), **USA** (Bedir et al., 2013)**, Netherlands** (Brounen et al., 2012), **Netherlands** (Wiesmann et al., 2011)**, Portugal**		

	(Pachauri, 2004), **India** (Leahy and Lyons, 2010), **Ireland** **Gas** (Curtis and Pentecost, 2015), **Ireland** **Energy** (Belaid and Rault, 2020), **Egypt**		
Home ownership (effect of owning a home)	**Electricity** (Huang, 2015), **Taiwan** (Taale and Kyeremeh, 2019), **Ghana** (Wyatt, 2013), **UK** (Wiesmann et al., 2011), **Portugal**	**Energy** (Rehdanz, 2007), **Germany** (Belaid and Rault, 2020), **Egypt**	
Number of rooms (effect of larger housing areas)	**Electricity** (Huang, 2015), **Taiwan** (Taale and Kyeremeh, 2019), **Ghana** **Gas** (Curtis and Pentecost, 2015), **Ireland**	**Electricity** (Bedir et al., 2013), **Netherlands** (Brounen et al., 2012), **Netherlands**	**Electricity** (Wiesmann et al., 2011), **Portugal**
Access to energy electricity and gas	**Electricity** (Rahut et al., 2016), **Bhutan** **LPG** (Rahut et al., 2016), **Bhutan** **Energy** (Alkon et al., 2016), **India**	**Traditional fuels** (Rahut et al., 2016), **Bhutan**	

Source*: Own elaboration based on the literature.*

The concept of energy poverty has been debated in recent years. (Sadath and Acharya, 2017) explain the lack of conceptual and methodological consensus on its definition, its determinants and the policy measures that could mitigate its impacts. According to (Modi et al., 2006), energy poverty can be defined as the lack of access to lighting services, food cooking with modern fuels, refrigeration, and air-conditioning or other sources to prevent climate discomfort at home. This is what is generally classified as a “multidimensional definition”. Multidimensional definitions are in general difficult to apply due to data availability, requiring specific data gathering and lacking comparability across studies.[4] Another strand of literature concentrates in what is generally classified as “objective” or “single-indicator measures”. The first attempt to find an “objective” measure was applied by (Boardman, 1991) in the UK, talking about "poverty by (access to) fuel" or "fuel poverty", when a household spent more than 10% of its income in the referred energy source.

More recently, other “objective” measures of energy poverty have emerged in developed countries, including the “Low income – High Consumption” (LIHC) index (Hills, 2012) which considers a household as energy poor when its energy bill is above the national median level, and its residual income is below the poverty line. This energy poverty definition has been extensively used in Europe (e.g. Campi et al. 2022) but its use has been limited in low-income countries (e.g. Belaid, 2020). Moreover, the use of the LIHC definition for lower income countries has been criticised (see Sy and Mokaddem, 2022). The main argument for this criticism is the need to better understand consumption patterns and their links with living conditions in countries with great inequality. We partially accommodate this criticism by studding energy consumption determinants before plunging into energy poverty, even if a

[4] (González-Eguino, 2015) presents a complete overview on energy poverty, its different definitions, ways of measurement as well as its implications.

multidimensional study would be a great complement to the analysis we do herein, provided the data was to become available.

3. Data and descriptive analysis

Herein we use the most recent Moroccan household survey published in 2019 with data from 2013-2014, which is the fifth national survey on household's consumption expenditures and living conditions conducted by the High Commission for Planning (HCP, 2019). Even if the survey was conducted about seven years ago, this paper provides original results for the North African region where a very limited number of studies have been published so far. The sample includes 15970 households that are representative for the whole country. The database collects household and dwelling characteristics, demographic information and annual expenditures by consumption good. In particular, energy expenditures (excluding transport) include: electricity, butane, wood, coal, plant residuals and other energy sources collected by the household itself. Income data are not collected so we use total expenditures as a proxy of income. Expenditures are converted from local currency to dollars using the exchange rate of 1MAD = 0.12$. As the survey was conducted from July 2013 to June 2014, we used the average exchange rate of 2013-2014 (The World Bank, 2020).

3.1. Quantitative variables

Descriptive statistics of quantitative variables are displayed in **Table 2**. Average energy expenditures (including electricity, butane, wood, coal, plant residuals and other energy sources collected by the household itself) are 447 $/y with a minimum expenditure of 14$/y and a maximum expenditure of 7924$/y. With respect to electricity, households spend on average 239 $/y with a minimum expenditure of 0$/y and a maximum expenditure of 3168$/y. Lower than electricity, butane expenditures reach on average 146$/y with a minimum expenditure of 0$/y and a maximum expenditure of 1364$/y. The distribution of each of all these expenditures is detailed in **Appendix A.1.**

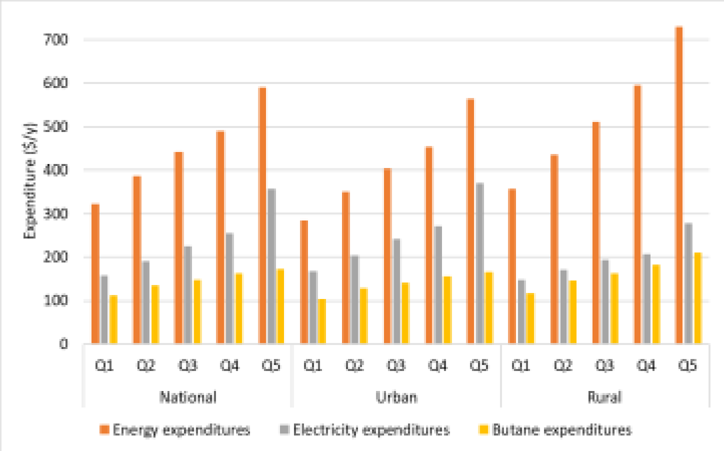
Table 2: Descriptive statistics of quantitative variables used in this study

	Unit	N	Mean	Std. Dev.	Min	Max
Family size	Integer	15970	4	2	1	6
Number of rooms	Integer	15970	3	2	1	15
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

***Source**: Own elaboration based on Household survey data*

Figure 1 displays household's average expenditures for energy, electricity and butane, by location and income quintile. It shows important patterns on fuel choices. Rural households spend more in energy than urban household due to higher expenditures in butane (and higher expenditures for other traditional fuels). However, for electricity, urban households tend to spend more than their rural counterparts do. In both locations, expenditures increase as income increases.

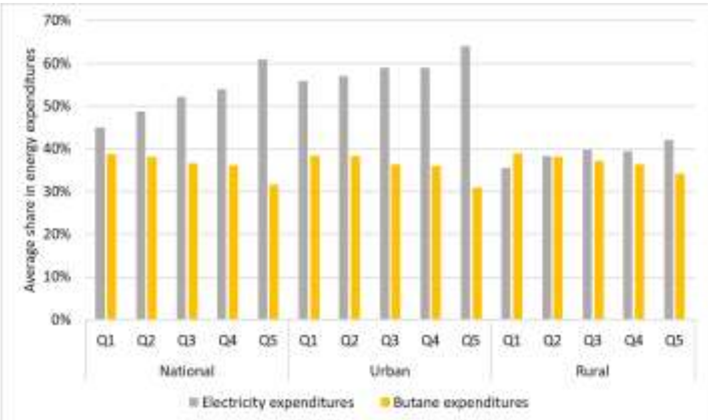
Figure 1: Average expenditures for energy, electricity and butane, with respect to location and income distribution



Source*: Own elaboration based on Household survey data*

Looking at the breakdown of energy expenditures between electricity and butane **Figure 2** show that the share of electricity in the energy budget increases along the income distribution. At the national level, the share of electricity in total energy expenditures ranges between 45% (Q1) and 61% (Q5). With respect to location, this share ranges between 56% (Q1) and 64% (Q5) for urban households and 35,5% (Q1) and 42% (Q5) for rural households. If the share of electricity in total energy expenditures increases as income increases, the opposite effect is observed for butane. At the national level, the share of butane in total energy expenditures ranges between 38,7% (Q1) and 31,6% (Q5). With respect to location, this share ranges between 38,4% (Q1) and 31% (Q5) for urban households and 38,9% (Q1) and 34,3% (Q5) for rural households. It is worth noting that if for urban households the share of electricity in total energy expenditures is always higher than the share of butane, whatever the quintile, this is not the case for rural households. Indeed, the share of electricity in total energy expenditures slightly exceeds the share of butane only starting from Q3 in rural areas.

Figure 2: Average share of electricity and butane expenditures in total energy expenditures with respect to location and income



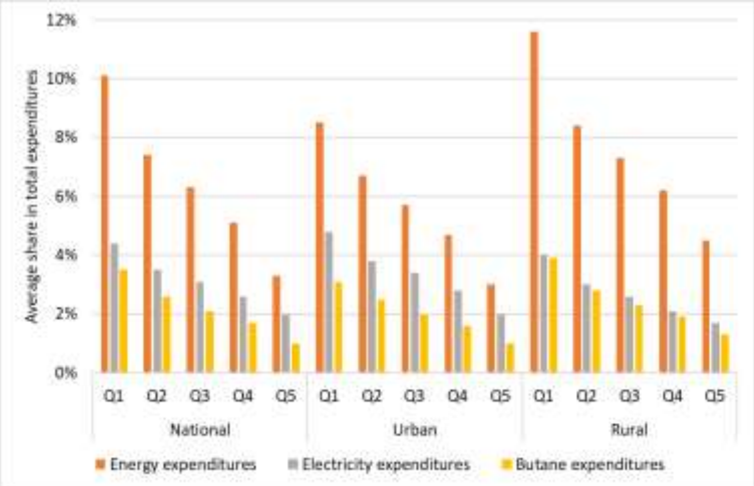
Source*: Own elaboration based on Household survey data*

Regarding affordability of energy, in total household’s expenditures **Figure 3** provides useful information about energy affordability. At the national level and regardless of location, the average share of total energy expenditures in total household’s expenditures ranges between 10,1% (Q1) and 3,3% (Q5). This share is higher for in rural areas. Rural households in Q1 spend about 11,6% of their income in energy.

At the national level, the average share of electricity expenditures in total household’s expenditures ranges between 4,4% (Q1) and 2% (Q5). For urban households, this share ranges between 4,8% (Q1) and 2% (Q5) whereas for rural households it ranges between 4% (Q1) and 1,7% (Q5).

At the national level, the average share of butane expenditures in total household's expenditures ranges between 3,5% (Q1) and 1% (Q5). For urban households, this share ranges between 3,1% (Q1) and 1% (Q5) whereas for rural households it ranges between 3,9% (Q1) and 1,3% (Q5).

Figure 3: Average share of energy, electricity and butane in total household's expenditures with respect to location and income



***Source**: Own elaboration based on Household survey data*

The previous description shows an important problem of affordability of energy. The extensive subsidies present in Morocco fail to make energy affordable for the first quintile and perpetuate a very regressive distribution of the budget shares of households in terms of energy spending. That is why herein we study determinants of energy consumption and energy poverty suggesting how the mandatory energy transition could constitute an opportunity to improve affordability for some households, liberating funds for better targeting energy subsidies to the poorest population.

3.2. Qualitative variables

Table 3 displays the list of qualitative variables used in this study.

Most of Moroccan households live in urban areas (65%). More than two thirds of them live in the North (64%). Most of households live in modern houses (51%) and are homeowners (71%). Nearly all households have access to the electricity network (97%). In addition, most of household heads are male (82%), aged between 45 and 70 years old (57%) and have no degree (69%) but are employed (73%).

The distinction between north and south regions is done based on the MASEN solar mapping[5]. The regional dummy captures the fact that, in the Northern regions (for example Rabat, Casablanca, Tangier) there are private electricity distributors, consumers are richer and the weather is milder. In the South most consumers are served by the national public utility (ONEE), consumers are poorer and the weather is hotter since it is closer to the dessert.[6]

Table 3: Descriptive statistic of qualitative variables. Frequency values indicate the ratio of total population falling in that category

Variable	Categories	N	Frequency
Location	Urban *(dummy=1)*	10380	0,65
	Rural	5590	0,35

[5] Regions in the North include most of big cities (in terms of economic activities and population) in Morocco.

[6] However, this spatial distribution is not always applied since the national utility ONEE distributes electricity to some households even in large cities.

Region	North *(dummy=1)* South	10167 5803	0,64 0,36
Gender of household's head	Male *(dummy=1)* Female	13068 2902	0,82 0,18
Age group of household's head	<25 years old 25-45 years old 45-70 years old > 70 years old *(reference category)*	149 4686 9052 2083	0,01 0,29 0,57 0,13
Employment status household's head	Active *(reference category)* Inactive Retired Annuitant/Other	11587 2847 1423 113	0,73 0,18 0,09 0,01
Education of household's head	No *(reference category)* Medium High	11057 977 3936	0,69 0,06 0,25
Ownership of dwelling	Owner *(reference category)* Renter Free housing Other type of ownership	11564 2715 1353 338	0,72 0,17 0,08 0,02
Type of house	Flat Villa Modern house *(reference category)* Traditional house Rural house Shantytown Other type of housing	1506 275 8149 629 4599 646 166	0,09 0,02 0,51 0,04 0,29 0,04 0,01
Access to electricity network	Yes *(dummy=1)* No	15428 542	0,97 0,03

Source*: Own elaboration based on Household survey data*

4. Methodology

To analyse the determinants of energy expenditures for Moroccan households, we consider three dependent variables: total energy expenditures, electricity expenditures and butane expenditures. Most papers investigating household's consumption based on survey data use OLS regression. Besides relying on strong assumptions, using a classical OLS model may result in misleading coefficients, especially when the response variable is skewed (Ewing and Rong, 2008).

The regression analysis for the two dependent variables, energy expenditures and butane expenditures, are carried out on the total sample size of 15970 households. For the dependent variable electricity expenditures, the sample size is reduced to include only households who have access to the electricity network (97% of households in the dataset) (see **Appendix A.2.** for a detailed explanation of household's access to electricity infrastructure).

With the purpose to estimate determinants of energy consumption, herein we use two alternative specifications, a quantile regression and a classical OLS approach. Let us consider a regression model with the following form:

$$y_i = x_i'\beta + \varepsilon_i$$

The coefficients estimated using a classical OLS approach are obtained as follows:

$$\min_{\beta \in R^k} \sum_{i=1}^{n} (y_i - x_i'\beta)^2$$

Where y is the endogenous variable, x is a vector of exogenous variables and β is the parameter vector to be estimated.

Since it is well known that elasticity of household's expenditures varies across income quintiles (Deaton, 1997), in order to explore the distributional effects of energy expenditures, rather than the average, we use a quantile regression model. Quantile regression has the advantage of being more robust to outliers and is more efficient than OLS in case of non-normal residuals (Koenker and Hallock, 2001). In addition, quantile regression may be useful to precisely identify the profile of high energy users and therefore to design targeted policies to reduce energy consumption in the residential sector. Developed by (Koenker and Bassett, 1978), quantile regression estimates the effect of independent variables on specific quantiles.

The difference between OLS and quantile regression is that OLS estimates the conditional mean while quantile regression estimates the conditional quantiles.

Let p be a number varying between 0 and 1 and Qp the p quantile of the distribution of a random variable y. In the quantile regression, β can be estimated for any quantile $p \in [0,1]$ by minimizing the following expression (Koenker and Bassett, 1978):

$$\min_{\beta \in R^k} \sum_{i=1}^{n} p(y_i - x_i'\beta)^2$$

Contrarily to the OLS method which estimates the regression slope by minimizing the squared of residuals, quantile regression estimates 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):

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

Results of the previous estimation, where β stands for the vector of explanatory variables per quintile, are presented in **Section 5**. The methodology is similar to (Huang, 2015).

To estimate the determinants of energy poverty we follow (Ogwumike and Ozughalu, 2016). We first regress "energy poverty" considering (Broardman´s, 1991) definition against the same independent variables we used for the previous regression model. Instead of using income, we use income quintile as a predictor, with "Q5" as a reference category. The logit model is as follows:

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

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 the household is energy poor, 0 otherwise and $(\frac{P_i}{1-P_i})$ is the odds ratio in favour of being energy poor.[7]

To examine the accuracy of the model, in **Appendix A.3** we plot the Receiver Operating Characteristics Curve (Wodon, 1997) that validates the fact that most coefficients in our model are significant.

Finally, 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. Generally, the economic attractiveness of PV installations is based on grid parity which occurs when the LCOE is less than or equal to the price of electricity from the grid. To calculate the LCOE we use the same formula as (Allouhi et al., 2019):

$$LCOE = \frac{Capex + \sum_{t=1}^{t=n} \frac{Opex_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{E_{,t}}{(1+i)^t}}$$

$$E_{,t} = S_{,t} \times (1-d)^t$$

$Capex$: Initial investment expenditures in $,
$Opex_t$: Annual operation and maintenance cost in $ in year t,
$S_{,t}$: Produced quantity of electricity during the first year of operation (kWh)
$E_{,t}$: Produced quantity of electricity in kWh in year t,
i : Annual discount rate,
n : Economic lifetime in year,
t : Year of lifetime.
d: Degradation rate per year applied to $S_{,t}$

Input data for LCOE calculation are summarized in Erreur ! Source du renvoi introuvable.**4**. Regarding investment costs of installing PV systems in Morocco, we obtain estimates of costs in 2020 from a local company called SEWT-Solar (SEWT, 2019) which has an experience of more than 20 years in the installation of solar systems in Morocco (UNEP DTU and Partnership, 2017).The first estimate is related to the installation of a 1,1 kWp system giving a cost of 2944 $. The second estimate concerns the installation of a 2,2 kWp PV[8] system giving a cost of 4512 $. Details of installation costs are displayed in **Appendix A.4.** To calculate the produced amount of electricity we assume a PV output or Yield of 1830 kWh/kWp/y (Ninja renewables database[9]). We use a reference discount rate of 7%.

Table 4: Input data for LCOE calculation

Input	Unit	Value	Source
$Capex$	$/kW	2944-4512	SEWT-Solar
$Opex_t$	$/kW	1,75% of $Capex$	(UNEP DTU and Partnership, 2017)
$S_{,t}$	kWh/kWp/y	1830	(Renewables Ninja, 2015)
i		7%	(UNEP DTU and Partnership, 2017)

[7] We have also perfomed a probit estimation that shows robust results. We have also tested alternative specifications where estimates and signs are consistent.

[8] The optimal power found for a large consumer (5755 kWh/y corresponding to 480 kWh/month) in Morocco is 2,1 kWp (Mbodji et al., 2015) which is close to the value obtained from the local installer

[9] https://www.renewables.ninja/. Hourly data of PV production using a performance ratio of 81%. Optimized slop and azimuth are retrieved from PVGIS database. The chosen location is Casablanca city.

n	years	25	(Allouhi et al., 2019)
d	%/y	0,2	(UNEP DTU and Partnership, 2017)

Finally, it is worth noting that in some papers energy expenditures are transformed to physical consumption while others keep original values in monetary consumption through expenditures. The conversion to physical consumption has the advantage of revealing more precisely the patterns of energy consumption of households. However, it is not directly available in our database. If detailed data on regional or district prices are not available, the general assumption of an average electricity price would lead to ambiguous results (hiding the potential heterogeneity between prices paid by households). For this reason, we will not consider this in our econometric estimation but, we will refer to electricity prices in **Section 5c** and to butane prices as well as the impact of subsidies on fiscal sustainability in **Appendix A.5.**

5. Results

a. Determinants of energy consumption

The empirical results for energy consumption are shown in **Table** . Quantile regression is estimated for the 25th, 50th and 75th quantiles. As a benchmark, results from an OLS regression are also displayed. Detailed plots of quantile regressions are displayed in **Appendix A.6.**

In line with the literature, **income** is a significant determinant of energy and electricity expenditures for all quantiles. Higher income is associated with higher expenditures in energy sources (Salari and Javid, 2017), (Taale and Kyeremeh, 2019), (Petersen, 1982). Our empirical results show that income elasticities for total energy expenditures range between 0,24 (25th) and 0.30 (75th). Income elasticity from OLS is 0,28. Regarding electricity, income elasticities range between 0,29 (25th) and 0,33 (75th) while income elasticity from OLS is 0,27. Finally, for butane expenditures, income elasticities range between 0,17 (75th) and 0,21 (25th). Income elasticity from OLS is 0,21. For energy and electricity, income elasticities are higher for higher consumers. However, for butane, income elasticities are higher for low consuming households.

Regarding **family size** measured as the number of members in the household, our results suggest that it has a significant and negative impact on total energy expenditures for all quantiles. The coefficients for household size range between -0,04 (75th) and -0,03 (25th). The OLS estimate is -0,03. Regarding electricity and butane, our results suggest that family size has a significant and positive impact on expenditures for all quantiles, in line with (Zhou and Teng, 2013) but contradicting the findings of (Taale and Kyeremeh, 2019). The impact of family size is higher for butane than for electricity but the magnitude of this impact decreases from low to high quantiles of the distribution. Regarding butane, the coefficients for family size range between 0,03 (75th) and 0,04 (25th). The coefficient from OLS estimation is 0,04. Finally, the coefficient for family size regarding electricity expenditures range between 0,01 (75th) and 0,02 (25th). The coefficient from OLS estimation is 0,02.

Our results suggest that the **number of rooms** has a significant and positive impact on energy, electricity and butane expenditures, for all quantiles, as households living in houses with a large number of rooms tend to have higher energy needs in comparison to houses with a small number of rooms. The coefficients range between 0,01 and 0,02. Our findings are in line with (Huang, 2015), (Curtis and Pentecost, 2015) but contradict the findings of (Bedir et al., 2013) and (Brounen et al., 2012).

With respect to **location,** our results suggest that living in urban areas is associated with lower energy and butane expenditures but higher electricity expenditures. Our results are in line with (Hasan and Mozumder, 2017) who found that urbans tend to use more cleaner energy sources such as electricity compared to rural who still consume traditional fuels. However, our findings are not in line with (Petersen, 1982) who found that living in urban area is associated with lower electricity expenditures. Regarding energy expenditures, our estimates range between -0,06 (75th) and -0,02 (25th). The OLS estimate is -0,05. Regarding butane, estimates range between -0,04 (50th) and -0,03 (25th). The OLS estimate is -0,04. Finally, for electricity, our estimates range between 0,05 (75th) and 0,06 (25th). The OLS estimate is 0,08.

The impact of **regions** is also statistically significant and positive across all quantiles. Living in the North is associated with higher expenditures in energy, electricity and butane. For butane, the coefficients range between 0,02 (75th) and 0,03 (25th). The OLS estimate is about 0,03. The coefficients are slightly higher for electricity, ranging between almost 0,04 for all quantiles and 0,05 (OLS). Regarding energy expenditures, the coefficients range between 0,01 (50th, 75th) and 0,02 (25th). The OLS estimate is 0,02. Our results are in line with (Filippini and Pachauri, 2004) and (Taale and Kyeremeh, 2019) who found that living in more developed regions is associated with higher energy expenditures.

Regarding the effect of **gender** of household's head, our results suggest that being a male is associated with lower energy and electricity expenditures, in line with (Taale and Kyeremeh, 2019) but contradicting the findings of (Belaid and Rault, 2020) and (Wang, 2016). Regarding energy, the coefficients are statistically significant in all quantiles, especially at the 50th quantile, reaching about -0,01 at this quantile. For electricity, gender is statistically significant only at the 50% quantile, reaching about -0,01. Regarding butane, our results suggest that male-headed households tend to spend more than females. The coefficients are statistically significant in all quantiles, especially at the 50% quantile, reaching about 0,02 at this quantile.

With respect to the **age** of household's head, our results show that compared to household heads aged more than 70 years old, those aged between 25 and 45 years old and those aged less than 25 years old spend less in energy, electricity and butane. This effect is significant in all quantiles and for all energy sources considered except for butane, for household heads aged less than 25 years old. Our findings are in line with (Pachauri, 2004) and (Rahut et al., 2016) but contradict the findings of (Yohanis et al., 2008) and (Leahy and Lyons, 2010). In particular, the effect of age on expenditures is stronger for heads aged less than 25 years old at the 25th quantile. The coefficients at this quantile are about -0,11 for energy, -0,12 for electricity expenditures and -0,21 for butane expenditures for this category of age. For heads aged between 25 and 45 years old, the coefficients are only statistically significant for energy and electricity. For this category of age and at the 25th quantile the coefficients are -0,02 and -0,05 for energy and electricity respectively. The coefficients for the category of age ranging between 45 and 70 years old are only significant for energy expenditures, at the 75th quantile, reaching a value of -0,02.

Regarding the **employment status** of household's head, our main results suggest a significant and positive impact of being inactive or retired on energy expenditures. Our results are in line with (Taale and Kyeremeh, 2019) and (Permana et al., 2015) who found that being employed has a significant negative impact on expenditures. For example, the coefficients related to the category "inactive" range between 0,01 (50th) and 0,02 (25th) for energy and 0,02 (25th) and 0,04 (75th) for electricity. However, for butane, being inactive has a significant impact on expenditures only at the 50th and 75th quantiles.

Looking at the effect of the **education level** of household's heads, our results suggest that having a higher education is associated with lower energy and butane expenditures but higher electricity expenditures. This result is in line with (Taale and Kyeremeh, 2019) and (Hasan and Mozumder, 2017). Having a high education degree has a significant impact on energy expenditures only at the 75th quantile. This impact of higher education is stronger at the 25th quantile for electricity (0,04) and at the 50th quantile for butane (-0,05). Education appears to have no significant impact on high electricity users.

Looking at the effect of house **ownership**, our results suggest that renters tend to spend significatively less in energy than homeowners. This finding is in line with (Wiesmann et al., 2011) but contradicts the results of (Belaid and Rault, 2020). The coefficients are about -0,03 for energy, between -0,02 (25^{th}) and -0,03 (50^{th}) for electricity and between -0,02 (75^{th}) and -0,04 (25^{th}) for butane expenditures.

Regarding the **type of house**, our main results suggest that households living in villas and traditional Moroccan houses tend to spend significantly more in energy and electricity but less in butane, compared to modern houses. Our results are in line with (Salari and Javid, 2017) and (Wiesmann et al., 2011). However, households living in apartments, rural houses and shantytowns tend to consume significantly less than those living in modern houses, depending on the quantile.

Finally, in line with (Alkon et al., 2016), our results suggest that **access to electricity** infrastructure has a significant and positive impact on energy expenditures, with a stronger effect at the 25^{th} quantile. The effect on butane expenditures is however not significant at the 75^{th} quantile.

The values for Adjusted R^2 are low varying between 18% and 24% but household surveys have generally low R^2 values. For example, (Kostakis, 2020) found a R^2 of 36% for electricity consumption in Greece.

Table 5: Quantile and OLS regression coefficients

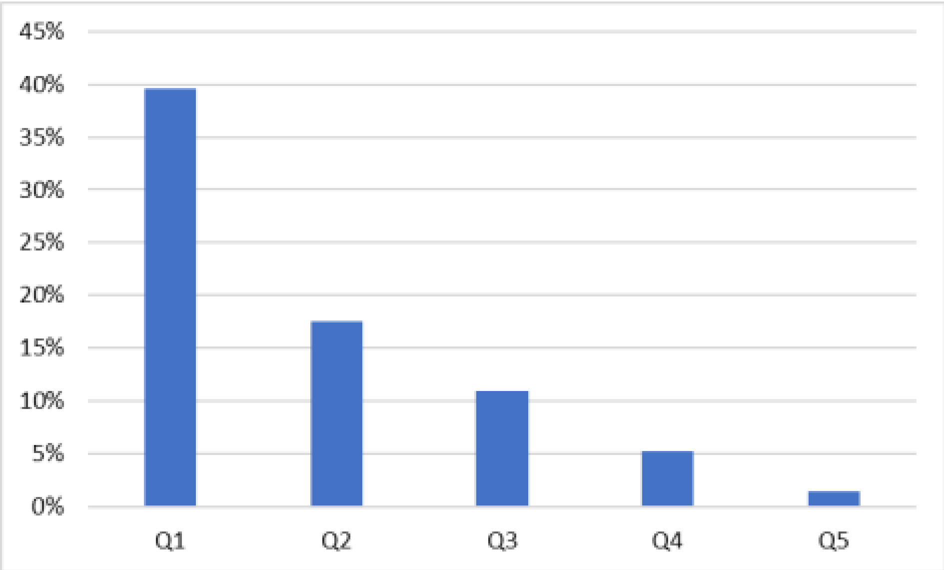
Regression results

	Dependent variable:											
	Energy expenditures				**Electricity expenditures**				**Butane expenditures**			
	Quantile regression			*OLS*	*Quantile regression*			*OLS*	*Quantile regression*			*OLS*
	25^{th}	50^{th}	75^{th}		25^{th}	50^{th}	75^{th}		25^{th}	50^{th}	75^{th}	
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)
45-70 years old	0.005	-0.007	-0.016**	-0.006	-0.008	-0.0005	-0.007	-0.002	0.003	0.002	0.010	0.005
	(0.006)	(0.006)	(0.007)	(0.005)	(0.007)	(0.007)	(0.007)	(0.009)	(0.007)	(0.007)	(0.007)	(0.006)
Annuitant	0.044*	0.040***	0.056***	0.064***	0.073***	0.061**	0.081***	0.068**	-0.031	-0.007	0.023	0.004
	(0.023)	(0.015)	(0.016)	(0.018)	(0.017)	(0.027)	(0.008)	(0.032)	(0.035)	(0.031)	(0.018)	(0.021)
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)
Retired	0.027***	0.015**	0.016*	0.020***	0.035***	0.038***	0.038***	0.047***	0.020**	0.019***	0.017*	0.016**
	(0.006)	(0.007)	(0.009)	(0.006)	(0.009)	(0.010)	(0.010)	(0.011)	(0.009)	(0.007)	(0.009)	(0.007)
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)
Medium degree	0.001	0.003	0.001	-0.001	0.027***	0.016***	0.021***	0.028***	-0.010	-0.009*	-0.007	-0.008*
	(0.004)	(0.005)	(0.005)	(0.004)	(0.006)	(0.006)	(0.006)	(0.007)	(0.006)	(0.005)	(0.006)	(0.005)
Free occupation	-0.024***	-0.007	0.006	-0.009	-0.015	-0.017**	0.002	-0.016	-0.030***	-0.016*	-0.021***	-0.024***
	(0.007)	(0.007)	(0.008)	(0.006)	(0.010)	(0.008)	(0.011)	(0.010)	(0.010)	(0.009)	(0.008)	(0.007)
Other occupation	-0.005	-0.011	-0.040***	-0.028**	-0.009	0.005	-0.002	0.013	-0.006	-0.008	0.010	-0.021
	(0.015)	(0.009)	(0.014)	(0.011)	(0.020)	(0.016)	(0.022)	(0.020)	(0.019)	(0.015)	(0.012)	(0.013)
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)
Other type of house	-0.049	-0.051*	0.005	-0.045***	-0.094***	-0.066***	-0.055	-0.090***	-0.122**	-0.031	-0.044*	-0.060***
	(0.036)	(0.029)	(0.024)	(0.016)	(0.012)	(0.022)	(0.043)	(0.028)	(0.054)	(0.042)	(0.023)	(0.019)
Rural house	-0.005	0.016*	0.039***	0.016**	-0.086***	-0.077***	-0.065***	-0.086***	-0.034***	-0.025***	-0.006	-0.031***
	(0.007)	(0.009)	(0.010)	(0.007)	(0.011)	(0.008)	(0.009)	(0.012)	(0.011)	(0.009)	(0.010)	(0.008)
Shantytown	-0.055***	-0.042***	-0.008	-0.033***	-0.110***	-0.091***	-0.076***	-0.237***	-0.024**	-0.008	0.001	-0.007
	(0.010)	(0.010)	(0.012)	(0.008)	(0.012)	(0.011)	(0.010)	(0.015)	(0.011)	(0.010)	(0.013)	(0.009)
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

b. Determinants of energy poverty

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 (using survey weights in our data), representing 14% of total households in the country, who mostly belong to the first income quintile Q1 (**Figure 4**). This percentage is high compared to other countries (see for example (Grottera et al., 2018)for Brazil and France and (Costa-Campi et al., 2019)for Spain).

Figure 4: Energy poor households by income quintile



Source*: Own elaboration based on Household survey data*

Table displays the estimates of the determinants of energy poverty in Morocco.

Our findings suggest that energy poverty is mostly explained by income as shown by the estimates of the **income** quintile variable. Our results, in line with (Mgwambani et al., 2018) for South-Africa, show that the odds of Q1 households of being energy poor are about 42 times the odds of Q5 households of being energy poor. The coefficients related to income quintile get smaller for higher income groups. For example, the odds of Q4 households of being energy poor are only 3,5 times the odds of Q5 households of being energy poor. Investigating the determinants of fuel poverty in Egypt and Jordan, (Belaid, 2020) found that the odds of being in fuel poverty for families in the first income quartile are 113 and 334 times the odds of families in the fourth quartile of being in fuel poverty in Egypt and Jordan respectively, all things being equal. This result is also in line with findings for high-income countries (Galvin and Sunikka-Blank, 2018).

In line with (Ismail, 2015) for South-Africa and (Belaid, 2020) for Egypt and Jordan, our results show that higher household's size increases the odds of being energy poor. We find that for one unit increase in **family size**, the odds of being energy poor increase by a factor of 1,1. However, our findings contradict the results of (Masuma, 2013) for the UK who found that small households are more likely to be energy poor than large families.

Regarding the **number of rooms**, our results show that for one unit increase in the number of rooms, the odds of being energy poor increase by a factor of almost 1,1. Looking at the **location** variable, our results suggest that the odds of urban households of being energy poor are smaller by a factor of 0,5 than the odds of rural households of being energy poor. This result in is line with (Ismail, 2015) and suggests that rural households have access to less efficient sources that may cost more than cleaner energy sources that are more accessible for urban households. However, this result contradicts the findings of (Belaid, 2020) who found that living in rural area lowers the odds of being in fuel poverty due to higher level of overall poverty in urban areas in Egypt and Jordan.

With respect to **gender**, we find that men's odds of being energy poor are smaller by a factor of 0,9 than female's odds of being energy poor. This finding is in line with (Ismail, 2015) but contradicts the results of (Tchereni, et al., 2013) for Malawi. With respect to the **employment status** of household's head, our results show that the odds of inactive households of being energy poor are 1,2 times the odds of active households of being energy poor. Regarding the **education** of household's head, our results suggest that higher educated heads are less likely to be energy poor compared to lower educated heads. This result is in line with (Belaid, 2020) who found that households heads with no education are more likely to be energy poor than educated heads. The odds of households with medium degree of being energy poor are smaller by a factor of 0,9 than the odds of households with no degree of being energy poor. For highly educated heads, this coefficient is 0,5. Our results are therefore in line with (Ismail, 2015) and (Kanagawa and Nakata, 2008) who found that higher education is associated with lower probability of being energy poor.

With respect to **house ownership**, our main result suggests that the odds of renters of being energy poor are smaller by a factor of 0,7 than owners' odds of being energy poor. In line with (Belaid, 2020) and (Poruschi and Ambrey, 2018), we find that the **type of dwelling** has a significant impact on energy poverty. Our main results show that the odds of being poor for households living in traditional houses are 1,6 times the odds of households living in modern houses of being poor. Also, the odds of being energy poor for households living in rural houses and shantytowns are almost 1,3 times the odds of households living in modern houses of being poor. However, households living in apartments are less likely to be energy poor.

Finally, the odds of households having **access to electricity** of being energy poor increase by a factor of 2 compared to households who do not have access to electricity. This result is interesting and in in line with (Ismail, 2015) who found that electrified households are more likely to be energy poor than households who are not. This result suggests that despite their access to the national grid, lower income households may suffer from energy unaffordability issues.

The pseudo-R^2 (McFadden adjusted) is 22%, which is lower than the ratio obtained in (Ismail, 2015) of 62%. The Hosmer and Lemeshow test (Hosmer and Lemeshow, 2000) gives a chi-square value of 14 with a p-value higher than 0,05, which validates the model. As we mentioned in the previous section, to examine the accuracy of the model, we plot the Receiver Operating Characteristics Curve (Wodon, 1997) which validates the fact that most coefficients are significant **(Appendix A.3.)**.

Table 6: Energy poverty regression results

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	

c. A just transition using Photovoltaic solar

In this section we explore to which extent the adoption of PV panels would help Morocco succeed a more just transition. The interplay between PV panel adoption by households and poverty is increasingly treated in recent academic literature. See, for example, (Crago et al., 2023) for a study on how racial disparity influences PV returns; (Best and Chareunsy, 2022) on the impact of income on PV adoption in Australia; or (Lee et al., 2022) on the impact of renewable adoption on energy poverty. Herein we choose a parametric approach to this question by studying grid parity of PV panels. With this purpose we first explain the way electricity prices are fixed and which is the price paid by each type of household. Then we compare that price with the cost of PV panels available in Morocco for household usage. This comparison allows us to show how it would be optimal for richest households to install panels and how the government would profit from that in subsidy savings. We discuss that, in the case of fading-out electricity subsidies completely for households consuming more than 300 kWh, PV panels would be competitive for almost all households consuming more than the median, freeing resources that could be used for targeted subsidies to the energy poor.

Electricity in Morocco is heavily subsidized. Subsidies for electricity are not precisely estimated but can be assumed to range between 8% to 43% depending on the household's category of consumption (Verme et al., 2014).

The tariff of electricity has the following components (ONEE, 2014):

- A fixed monthly fee related to the location and the maintenance of the electricity connexion. Fees depend on the type of meter installed. Higher capacities are associated to higher fees (**Table 7**).

Table 7: Fixed electricity fees ($/month)

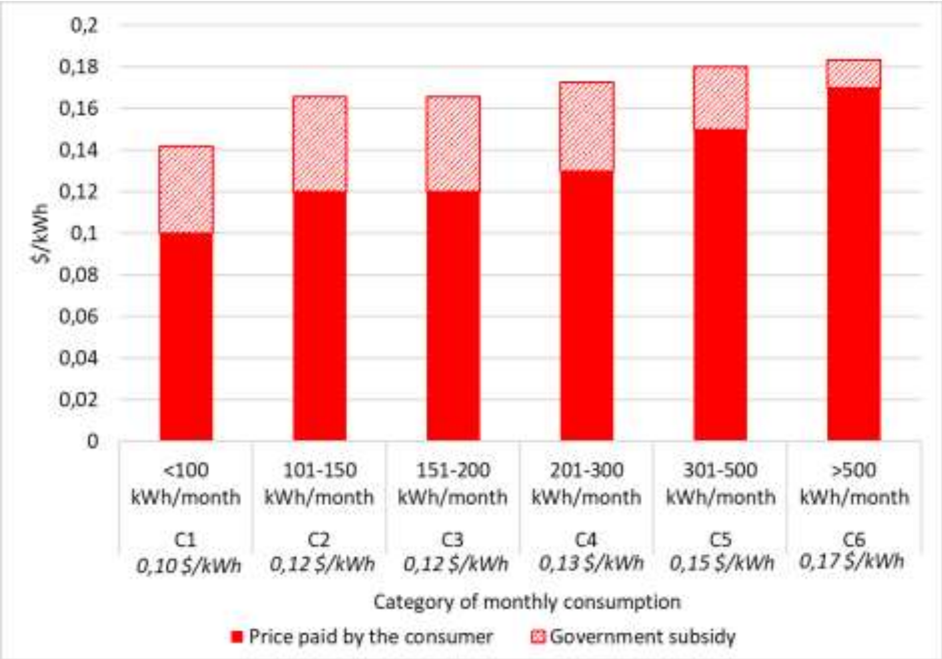
$/month (including a VAT of 14%)	Installation of the meter	Maintenance
2 wires (5 à 20 A)	1,1	1
4 wires (5 à 15 A)	1,1	2
4 wires (20 à 60 A)	3,5	2

Source: (ONEE, 2014)

- A variable fee related to the monthly consumption of electricity. The national utility ONEE divides household's monthly consumption in six categories C1 to C6 corresponding each to a range of consumption. For each category of consumption, a specific variable price ($/kWh) is associated. Electricity prices considered in this study are those applied by ONEE (ONEE, 2014). On average, prices fixed by private distributors are not too different from those of ONEE for households in categories C1 to C4 (less than 300 kWh/month) but are slightly higher for consumers in C5 and C6 (UNEP DTU and Partnership, 2017). **Figure** displays variable electricity prices (based on ONEE prices) including a VAT of 14%. As shown in this figure, electricity is subsidized for all households, whatever the consumption category. (Verme and El-Mesnaoui, 2015) found that for households consuming less than 100 kWh/month (C1), unit subsidies represent almost 43% of the unsubsidized price whereas for households consuming more than 500 kWh/month (C6), subsidies represent only 8%.

- Taxes: a tax for the audio-visual sector that is proportional to the variable monthly consumption but is capped at 11$/month (scale of taxation not available). Households consuming less than 200 kWh/month are exempted from this tax (Lydec, 2012).

Figure 5: Electricity prices for each category of monthly electricity consumption (with and without subsidies)



Source*: Own elaboration based on data from ONEE* (ONEE, 2014) *and* (Verme and El-Mesnaoui, 2015)*. Prices under each consumption group refer to subsidized prices paid by consumers*

On average, Moroccan households spend 239 $/y to satisfy their electricity needs. As an approximation, and based on household's electricity tariffs displayed on the national utility ONEE website[10] (average price of electricity of 0.13 $/kWh)[11], we find that the average electricity consumption of a Moroccan household would be around 1838 kWh/year[12] which is equivalent to almost 153 kWh/month. However, average household's electricity consumption calculated based on (IEA, 2020) and on the number of households provided in (Centre d'Etudes et de Recherches Démographiques, 2017) for the year of our survey results in an average consumption of 3952 kWh per year, which almost doubles our results. This difference may be justified by the lack of accuracy in household survey data (especially for electricity) which calls for high cautious in comparing household's consumption based on an average electricity price.

Even if electricity is heavily subsidized in Morocco, we have shown it is still unfordable for many households, having 14% of energy poverty. One way for households to reduce their electricity expenditures is to produce their own electricity using solar panels. Not only it allows households to prevent from future increase in electricity prices (plausible due to the financial situation of the national utility ONEE and with the Ukranian war), but it can also reduce energy poverty. For example, in Korea, solar PV helped to reduce energy costs of low-income families, especially for households consuming less than 280 kWh/month (Lee and Shepley, 2020).

[10] http://www.one.org.ma/FR/pages/interne.asp?esp=1&id1=3&id2=113&id3=158&t2=1&t3=1

[11] As mentioned earlier, there are 6 tariffs in the residential sector: < 100 kWh/month: 0.1 $/kWh; 101< …< 150 kWh/month: 0.12$/kWh; 101< …< 150 kWh/month: 0.12$/kWh ; 201<…<300 kWh/month: 0.13 $/kWh, 301<…<500:0.15 $/kWh; >500 kWh/month: 0.17 $/kWh. These tariffs include a 14% VAT.

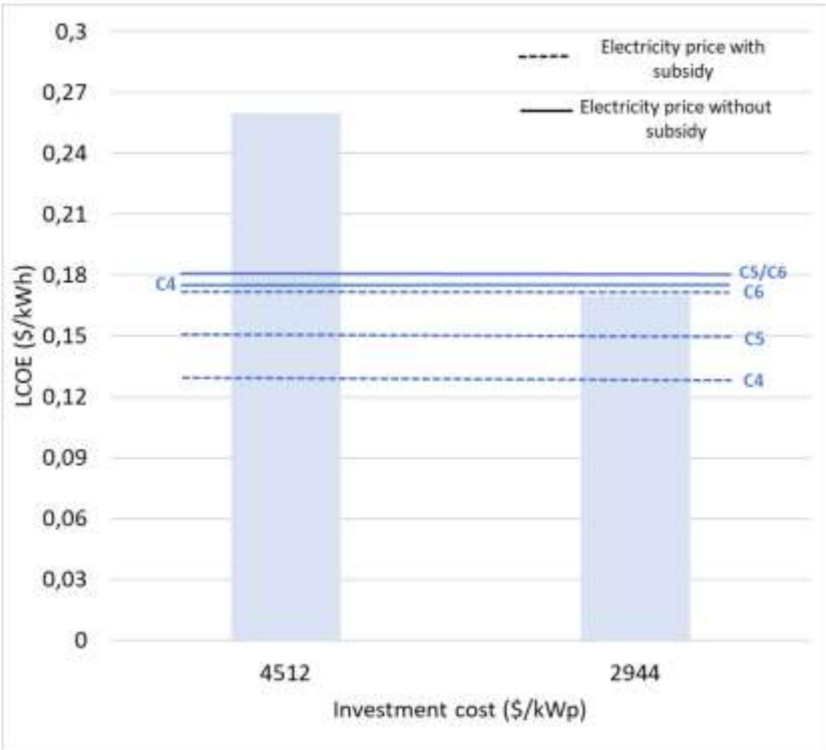
[12] In Brazil the average electricity consumption per household is 1860 kWh per year whereas it reaches 5500 kWh per year in France (Grottera et al., 2018)

Morocco has very good solar resources, but the penetration of decentralized solar energy is still weak compared to its neighbours (Tunisia) or other countries with even lower solar endowment (Germany, France). Ten years after the 13-09 law on renewable energies (2010), and after the amendments proposed in the law 48/15 (2016), the regulatory framework on decentralized renewable energy is still incomplete. The conditions of surplus energy injection on the low voltage grid by residential consumers are still under debate between the national utility ONEE, the ministries and the distributers, which slows down the take-off of rooftop solar PV (IEA, 2019).

The results regarding the attractiveness of solar PV for households in Morocco show that LCOE ranges between 0,17 $/kWh and 0,26 $/kWh, which is higher than values obtained in Spain or South Africa (0,10 $/kWh) but closer to LCOE values found for California (0,17 $/kWh) (IRENA, 2019).[13]

Comparing the LCOE with electricity prices by category of electricity consumption in **Figure** , we find that PV achieves grid parity only for households consuming more than 500 kWh/month (category C6 of consumption) for investment costs lower than 2944 $/kWp. However, if electricity prices without subsidies are considered, PV is attractive for households consuming more than 300 kWh/month (households in categories of consumption C4, C5 and C6, which includes all household consuming more than the median, which is well above 300 kWh/month). For an investment cost of 4512 $/kWp, PV does not achieve grid parity for all households both in case of subsidized and non-subsidized electricity prices.

Figure 6: Grid parity in case of subsidized and non-subsidized electricity prices



Let us now focus on grid parity with current prices. We can then use the household survey data to determine the proportion of residential electricity consumption that comes from households in C6. To do so, we first determine the minimum annual electricity expenditure for a household who belongs to this class. The minimum annual electricity expenditure for a household in C6 is: (500 kWh/month×0,17$/kWh×12) + 12×(3,5$/month + 2$/month) + (11×12) which is about 1284 $/y. Looking at the distribution of household's electricity expenditures from the survey data, we find that

[13] As is customary, we perform an LCOE sensitivity analysis. Results on the cost breakthrough of the panels are displayed in **Appendix A.4** and the sensitivity analysis is in **Appendix A.7.** for a 1,1 kWp system.

8774 households (using survey weights) spend more than 500 kWh/month. Most of these households are in Q5, active, live in an urban area, in Northern regions and are owners of villas or modern houses.

To satisfy its electricity consumption, a household from C6 would require the installation of: 500×12 (kWh/y) ÷ 1830 (kWh/kWp/y) which gives 3,3 kWp. Therefore, the minimum installed capacity if all households in C6 for which PV is today competitive is 3,3 kWp x 8774 which gives about 30 MWp.

Knowing that for households in C6, the unsubsidized electricity price is about 0,18 $/kWh, we can conclude that if these households for which PV is economically attractive adopt PV systems, the government would save a minimum annual amount of 526440$[14]. These savings could be, for example, reallocated to households in the first income quintiles to address energy poverty issues. If more households namely in C3, C4 and C5 adopt PV panels, which becomes competitive only if subsidies disappear, the amount of savings will further increase. In this sense, increasing electricity prices would not only contribute to recover part of the national utility costs but would also send a signal to large consumers for which PV today is competitive.

6. Conclusion

In order to design a targeted residential energy policy that promotes a just transition to solar energy while encouraging the adoption of energy saving behaviour, the understanding of electricity demand based on household's profiles is necessary.

Herein we investigate the determinants of energy consumption in the residential sector in Morocco using the most recent Moroccan household survey published in 2019. The results of our econometric estimations show that income elasticities vary between 0,17 and 0,33 depending on the energy source considered. For total energy and electricity, income elasticities are higher for richer consumers. However, for butane, income elasticities are higher for low consuming households. Aside from income, we find that socio-demographic attributes of household's head as well as dwelling attributes have a significant impact on energy expenditures. In particular, we find that living in urban areas in traditional houses and villas with a more educated household's head is associated with higher electricity expenditures but lower butane expenditures. In addition, male-headed households are associated with lower electricity expenditures but higher butane expenditures.

Regarding affordability, our main results suggest that 14% of Moroccan households are energy (or fuel) poor when considering Broadman (1991)´s definition i.e. spending more than 10% of their expenditures to satisfy their energy needs. We also find that households who are more likely to be energy poor are low income households with large family size who own houses in rural areas with a large number of rooms and headed by inactive men with no education. These results could be major entry points in determining the most efficient policy interventions to mitigate energy poverty in the country.

Finally, looking at the economic attractiveness of solar electricity in the residential sector as a mean to increase energy affordability and shield population from further increases in electricity prices, our main findings suggest that solar electricity is attractive only for households consuming more than 500 kWh/month. We also find that if all households for which PV is competitive actually install, the minimum installed capacity would reach about 30 MWp. With the installation of this capacity, the government would save a minimum annual amount of around half a million dollars in energy subsidies. Moreover, if subsidies for households consuming more than 300 kWh/month are eliminated, solar panel become competitive also for them, potentially creating important savings for the central government. These savings could be allocated to households in first income quintiles to address energy poverty issues,

[14] Resulting from the following calculation: 500 × 12 × 8774 × 0,01.

for example, to finance solar panels in newly built constructions dedicated to low- and middle-income households, contributing at the same time, to achieve Morocco´s energy transition objectives.

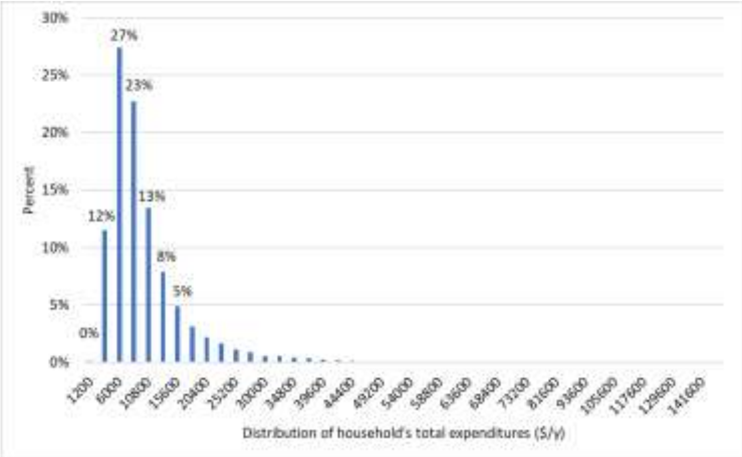
This study has few limitations. First, in terms of data availability, the database does not cover major drivers such as the stock of appliances, isolation of buildings, degree-days, energy prices and other variables related to the household's behaviour towards clean technologies and efficient appliances. In addition, data used in this paper, even in the most recent, is from few years back and things may have changed since then. There is a crucial need to regularly conduct surveys to explore the evolution of energy demand and energy poverty determinants over the years and to better design future policies to succeed a just energy transition.

A. Appendices

A.1. Distribution of total expenditures, energy expenditures, electricity expenditures and butane expenditures by income group and location

The distribution of total expenditures is displayed in **Figure** . It shows that 88% of households spend less than 15600$/y.

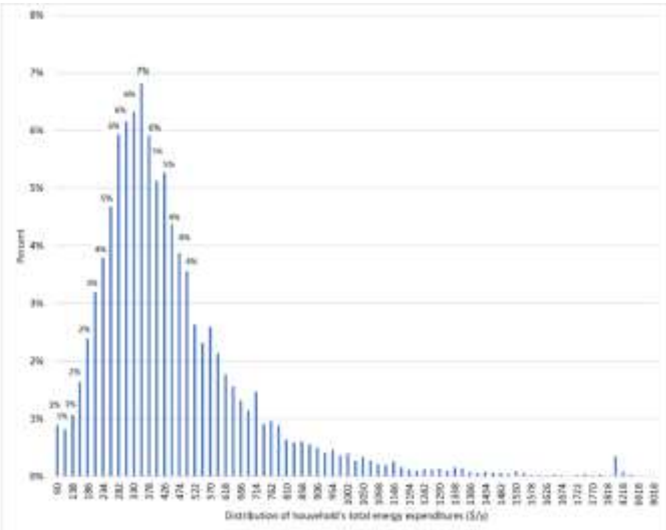
Figure 7: Distribution of total expenditures



***Source**: Own elaboration based on Household survey data*

The distribution of total energy expenditures is displayed in **Figure 8**. It shows that 50% of households spend less than 378$/y.

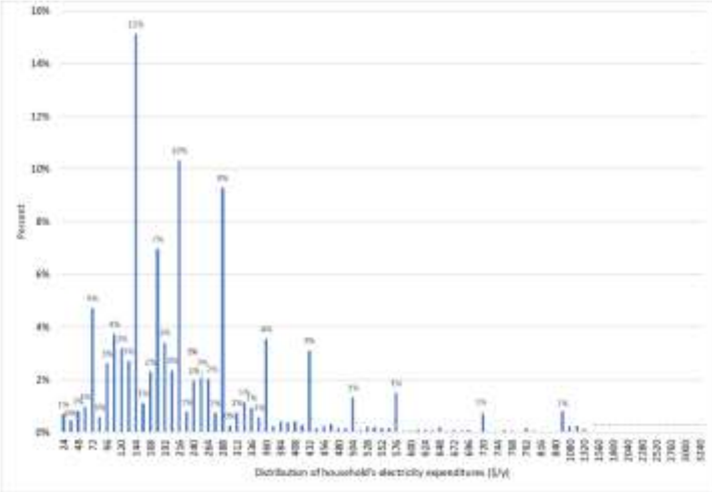
Figure 8: Distribution of total energy expenditures



***Source**: Own elaboration based on Household survey data*

The distribution of total electricity expenditures is displayed in **Figure 9**. It shows that 50% of households spend less than 200$/y.

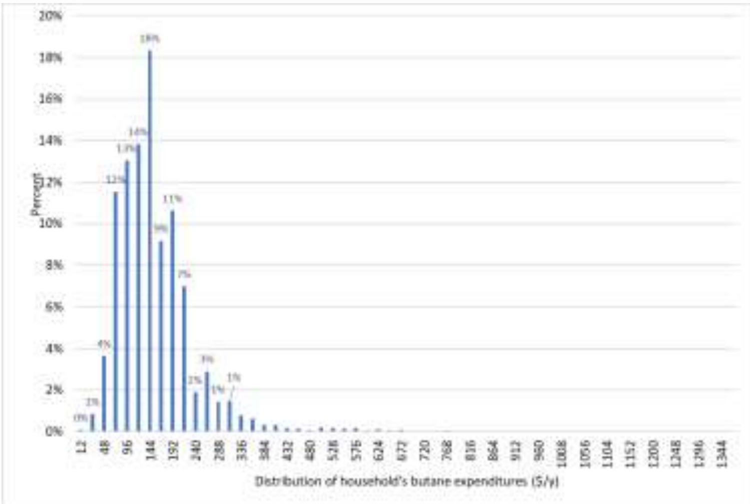
Figure 9: Distribution of electricity expenditures



Source*: Own elaboration based on Household survey data*

The distribution of total butane expenditures is displayed in **Figure 10**. It shows that about 62% spend less than 144$/y.

Figure 10: Distribution of butane expenditures



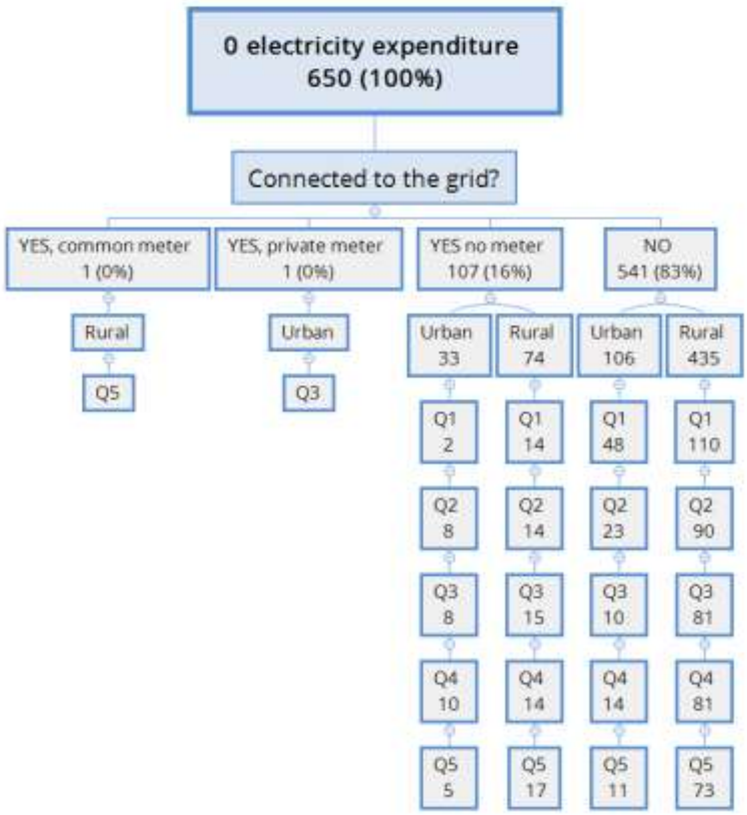
Source*: Own elaboration based on Household survey data*

A.2. Electricity expenditures

The sample collects data for 15970 households. Among them, 650 observations have 0 electricity expenditures. As displayed in Erreur ! Source du renvoi introuvable.**11,** the main reason for this null consumption is the absence of electric network connection especially in the rural area, across all income quintiles. The second reason of null electricity expenditure is due to the absence of electric meters even if households are connected to the grid. This phenomenon is common mainly in rural areas, across all income quintiles but is also observed in urban areas. Electricity may still be unfordable for these households. Even if they are grid connected, these households prefer using other energy sources. Finally, 2 households who are connected to the grid and have a meter have also null electricity expenditures. One lives in the urban area, has a private meter and belongs to the third urban quintile whereas the other lives in rural areas, has a shared meter and belongs to the richest rural quintile.

As the paper investigates the pattern of electricity expenditures in the residential sector, all households with 0 electricity expenditures and without a grid connection are excluded from the dataset which is finally left with 15428 households that are connected to the electricity network. Households with 0 electricity expenditures but who are connected to the network are not excluded as it can reveal household's preferences in the choice between different energy sources. It should be noticed that only one household has a positive expenditure in electricity while he is recorded as not having an electric connection. He belongs to the first rural quintile and spends around 7% of its income in electricity. It can be inferred that either the survey agent made a mistake in reporting the network connection output or that the household misunderstood the survey agent question or that he uses another source of electricity generation without being connected to the grid. This household is not excluded from the dataset.

Figure 11: Zero electricity expenditures in the sample

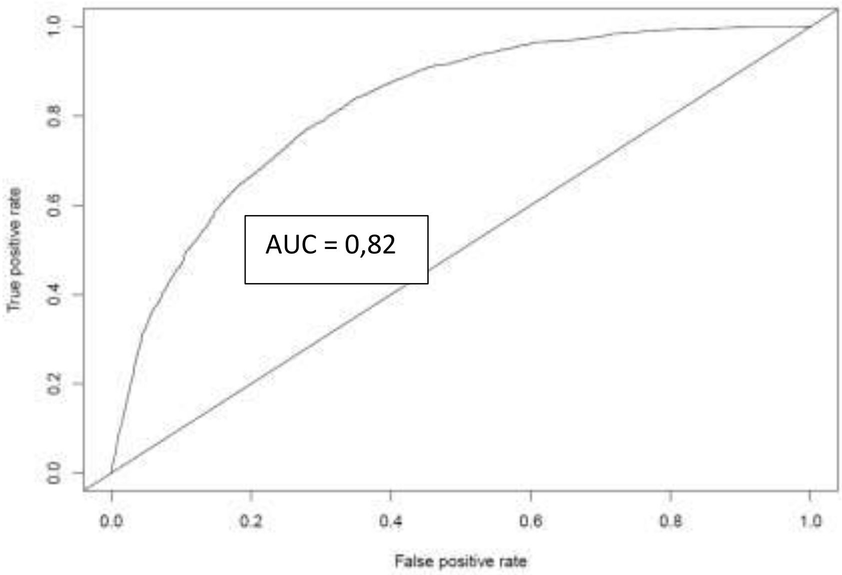


***Source**: Own elaboration based on household survey data*

A.3. Receiver Operating Characteristics Curve

This curve is constructed by plotting the true positive rate against the false-positive rate **(Figure 12)**. The ROC curve is far from the 45-degree diagonal line with an area under curve (AUC) of 0,82. This is similar to the result found in (Belaid, 2020) for Egypt. The AUC value may range from 0 (no predictive ability) and 1 (perfect discrimination).

Figure 12: ROC curve of the logistic model



Our results suggest that except for age and region, most coefficients are statistically significant.[15]

A.4. Cost breakdown of two residential PV systems

Erreur ! Source du renvoi introuvable.**8** displays the estimates of two PV systems costs in Morocco in 2020 from a local company called SEWT-Solar (SEWT, 2019) which has an experience of more than 20 years in the installation of solar systems in Morocco (UNEP DTU and Partnership, 2017).

Table 8: Cost of installed PV systems in the residential sector in Morocco

Cost ($) including Value Added Tax	1,1 kWp system	2,2 kWp system
PV module		
PV module	528	955
Balance of System (BoS)		
Inverter	950	1650
Support	158	317
Platform	53	106
Wiring and AC protection	158	158
Wiring and DC protection	238	238
Energy management	396	495
Installation and operation	462	594
Total cost of the PV system		
Total cost of the PV system	2944	4512

The inverter is the most costly part of the total cost of the installed system (more than one third), followed by solar modules (about 20%).

[15] For some categorical variables, only specific modalities are statistically significant such as the activity of household's head, the type of housing and the ownership status of the house.

A.5. Butane subsidies

Contrarily to electricity, the price of butane for households has been fixed for several years at 40MAD (about 4,8 $) for a bottle of 12kg, which corresponds to 0,4$/kg of butane. Households spend on average 146$/y in butane, that is, on average Moroccan households consume about 30 bottles of butane per year, or 2 bottles of 12 kg per month.

As displayed in Erreur ! Source du renvoi introuvable., butane subsidies represented 1% of GDP in 2014 and about 66% of the real cost of butane (Ministère de l'économie, des finances et de la réforme de l'administration, 2020). Because of the financial burden it represents, the government intends to reform this subsidy (IEA, 2019) limiting it only to low-income households. However, because of its social implications, the reform of butanes subsidies may prove to be difficult.

Table 9: The cost of butane subsidies in Morocco

% of subsidy in real cost	66
% of retail price in real cost	44
Subsidies in 2014 (billion dollars)	1.5
% of butane subsidies in GDP in 2014	0,01

Source*: (Ministère de l'économie, des finances et de la réforme de l'administration, 2020)*

As in Morocco, other developing countries have strong butane subsidies. For example, in Ecuador, the government spent about 716 million dollars in butane subsidies (1% of its GDP) in 2014, providing a subsidy of 11.5$ per butane cylinder of 15kg. In Ecuador, the retail price of a 15kg cylinder of butane is around 1.6$ (Gould et al., 2018). This price has not changed since 2001. Butane is more subsidized in Ecuador (88% of the real cost) than in Morocco in 2014 but the fiscal burden is rather similar as butane subsidies represented almost 1% of GDP in both countries in 2014. Subsidies to butane are to be reformed and substituted in the verge of an energy crisis and transition. Herein we contribute on the discussion on the way those subsidies should be faded-out.

A.6. Plots of quantile regression results

Erreur ! Source du renvoi introuvable. displays quantile results for energy expenditures. **Erreur ! Source du renvoi introuvable.** displays quantile results for electricity expenditures. **Erreur ! Source du renvoi introuvable.** displays quantile results for butane expenditures.

Figure 13 : Plots of quantile regression results for energy expenditures

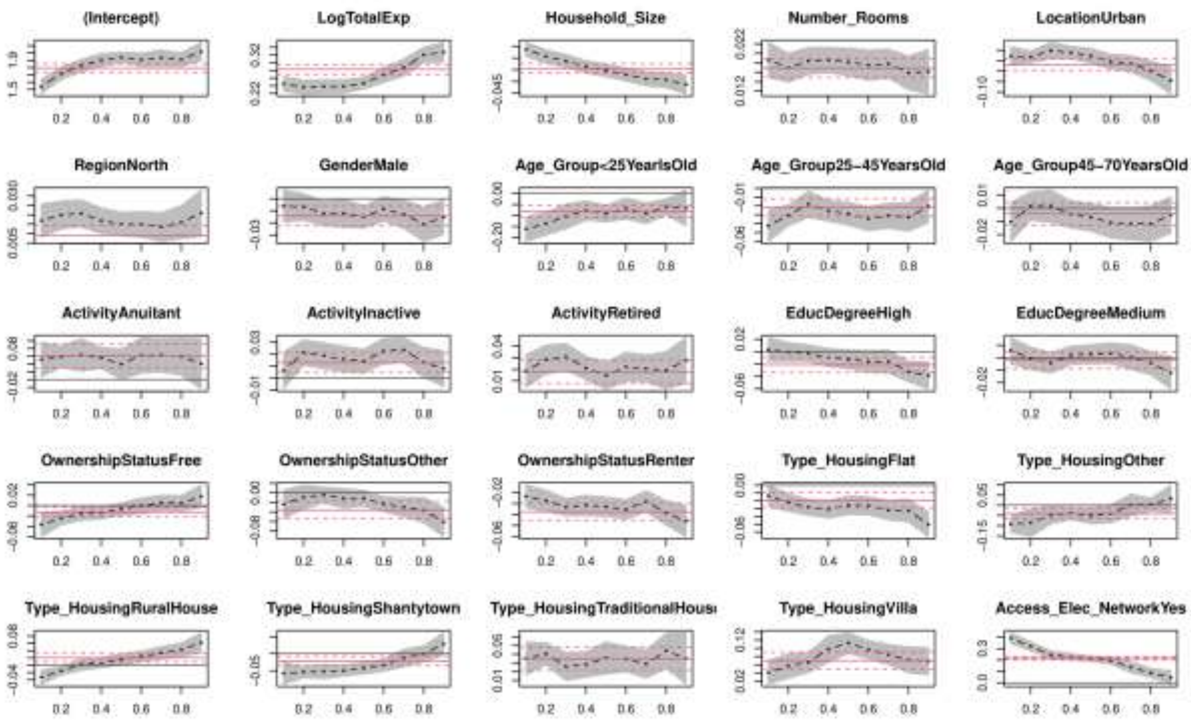


Figure 14: Plots of quantile regression results for electricity expenditures

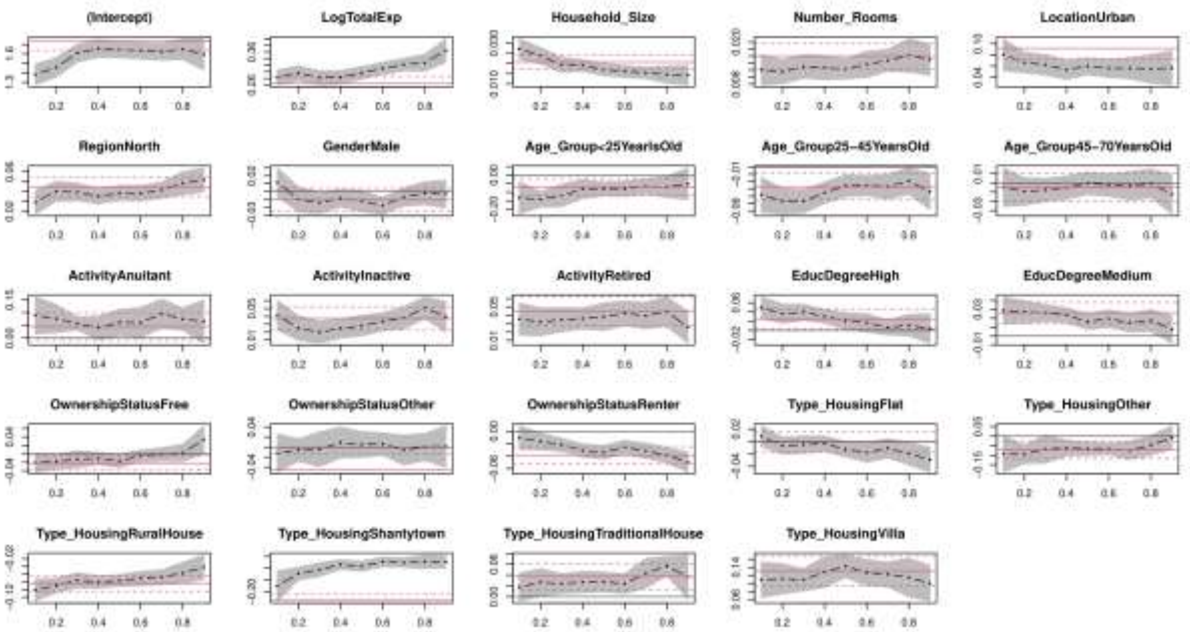
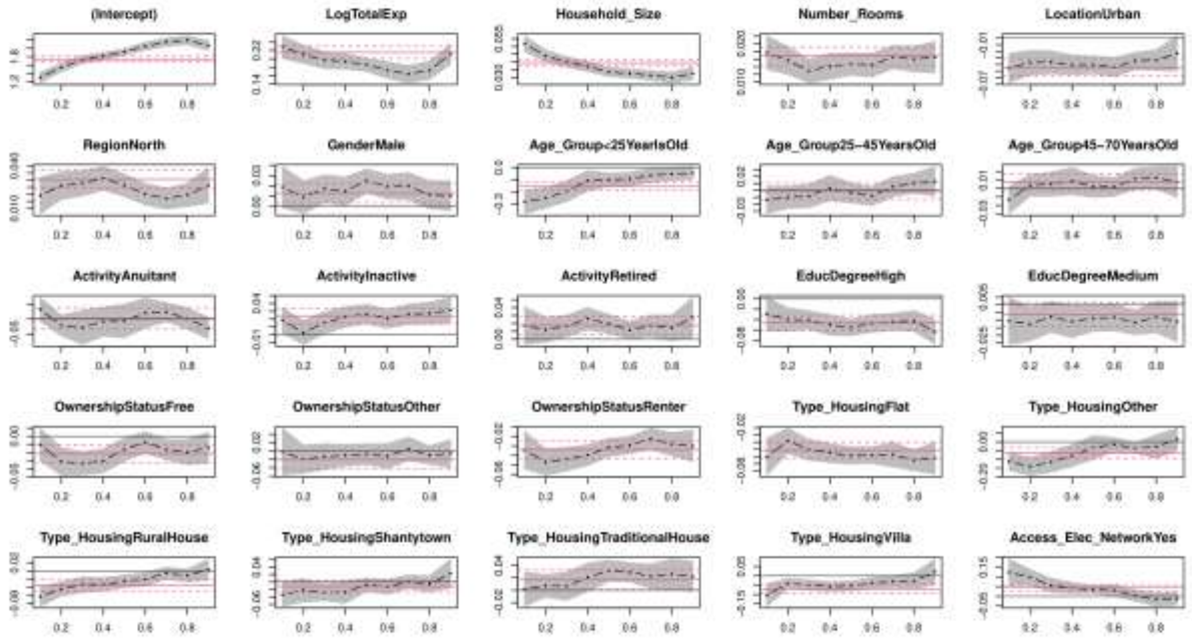


Figure 15: Plots of quantile regression results for butane expenditures

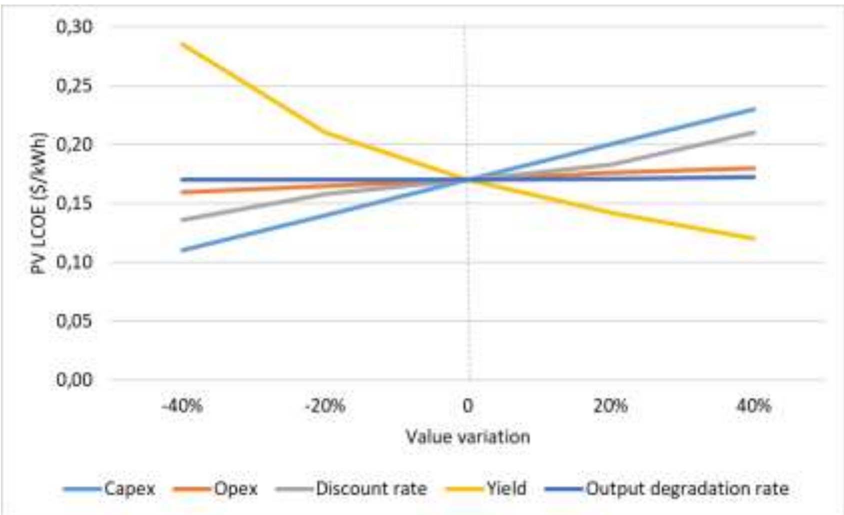


A.7. PV LCOE sensitivity analysis

As PV LCOE is highly dependent on assumed input values, we conduct a sensitivity analysis by varying initial input values listed in Erreur ! Source du renvoi introuvable.**8** in a range of +/-40% for a 1,1 kWp system. A sensitivity analysis can provide useful insights in uncertainties related to input assumptions of the parameters (Branker et al., 2011), (Veldhuis and Reinders, 2015).

As displayed in **Erreur ! Source du renvoi introuvable.16**, PV output, Capex and discount rate are the most determining factors. The reduction in the PV output or yield leads to higher PV LCOE. Low discount rates reduce the PV LCOE and the drop of Capex also lowers PV LCOE. The decrease in the cost of installed PV systems in the residential sector driven by technological improvement and increased cumulative capacity would further contribute to reduce the PV LCOE.

Figure 16: PV LCOE sensitivity analysis



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