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TECHNO-ECONOMIC ASSESSMENT OF OPTIONS FOR DOMESTIC WATER HEATING IN THE ECUADORIAN CITY OF CUENCA

Evaluación Tecno-económica de alternativas para calentamiento doméstico de agua para la ciudad ecuatoriana de Cuenca

Avaliação técnico-econômica de alternativas para aquecimento doméstico de água na cidade equatoriana de Cuenca

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ABSTRACT

INTRODUCTION. Homes in the Andean region of Ecuador, due to the relatively cold ambient temperature, require energy services such as hot water in a daily basis along the year. In that context, the preferred technologies used for such purpose run on LPG, mainly, due to its low cost as it is highly subsidized. This situation poses certain challenges for the energy policy of the country. **OBJECTIVE.** This case study aims to discuss more sustainable alternatives to obtain hot water for household use in the context of the Andean city of Cuenca. **METHOD.** Firstly, solar and meteorological data has been processed to characterize local conditions. Then, different technologies able to provide hot water have been simulated. Further, an economic analysis was performed to determine costs per unit of energy required. **RESULTS.** The use of subsidized LPG reduces the real cost of water heating between 47% and 72% depending on the daily levels of consumption. In the event of a subsidy removal, electric tankless water heaters, along with reduced electricity tariffs, become competitive for levels of consumption up to 120 liters per day. For higher levels of consumption solar thermal systems or heat pumps may become viable only when providing rebates **DISCUSSION AND CONCLUSIONS.** The presence of benefits of scale among levels of consumption need to be regarded when designing incentives for energy services such as domestic hot water.

Keywords: Water heating, cost, subsidies

RESUMEN

INTRODUCCIÓN. Los hogares de la región Sierra de Ecuador, debido a la presencia de temperaturas relativamente bajas, demandan diariamente servicios energéticos como agua caliente a lo largo del año. En ese contexto, las tecnologías preferidas para ese propósito utilizan GLP, debido principalmente a su bajo costo ya que es altamente subsidiado. Esta situación conlleva ciertos retos para la política energética del país. **OBJETIVO.** El presente caso de estudio apunta a exponer alternativas más sustentables para abastecer de agua caliente a hogares de la ciudad andina de Cuenca. **MÉTODO.** Datos meteorológicos y de radiación solar fueron procesados para caracterizar las condiciones locales. Luego se efectuaron simulaciones de tecnologías capaces de proveer agua caliente de forma centralizada. Posteriormente se llevó a cabo un análisis económico para determinar los costos por unidad de energía requerida. **RESULTADOS.** La utilización de GLP subsidiado reduce el costo real del calentamiento de agua entre el 47% y el 72% dependiendo los niveles diarios de consumo. En el evento de la eliminación de los subsidios, la opción de calefones eléctricos junto con tarifas eléctricas reducidas se vuelve competitiva para niveles de consumo de hasta 120 litros por día. Para demandas más altas, tecnologías como sistemas solares térmicos o bombas de calor pueden ser viables en caso de que se provean rebates significativos. **DISCUSIÓN Y CONCLUSIONES**. La aparición de beneficios de escala entre niveles de consumo debe ser observada al momento de diseñar incentivos para servicios energéticos como el agua caliente para uso doméstico.

Palabras clave: Calentamiento de agua, costo, subsidios

RESUMO

INTRODUÇÃO. As residências na região andina do Equador, devido à temperatura ambiente relativamente fria, necessitam de serviços de energia como água quente diariamente ao longo do ano. Nesse contexto, as tecnologias preferidas utilizadas para esse fim são as que utilizam GLP devido ao seu baixo custo pois é altamente subsidiado. Esta situação coloca certos desafios à política energética do país. **OBJETIVO**. Este estudo de caso visa discutir alternativas mais sustentáveis para a obtenção de água quente para uso doméstico no contexto da cidade andina de Cuenca**. MÉTODO**. Primeiramente, foram processados dados solares e meteorológicos para caracterizar as condições locais. Em seguida, foram simuladas diferentes tecnologias capazes de fornecer água quente. Além disso, foi realizada uma análise económica para determinar os custos por unidade de energia. **RESULTADOS**. A utilização de GPL subsidiado reduz o custo real do aquecimento de água entre 47% e 72% dependendo dos níveis diários de consumo. Em caso de retirada do subsídio, os aquecedores elétricos de água sem tanque, juntamente com as tarifas de energia elétrica reduzidas, tornam-se competitivos para níveis de consumo de até 120 litros por dia. Para níveis de consumo mais elevados, os sistemas solares térmicos ou bombas de calor podem tornar-se viáveis apenas quando oferecem descontos. **DISCUSSÃO E CONCLUSÕES**. A presença de benefícios de escala entre os níveis de consumo deve ser considerada ao conceber incentivos para serviços energéticos, como o água quente de uso doméstico.

Palavras-chave: Aquecimento de água, custo, subsídios

INTRODUCTION

In broad terms, Ecuador is a country characterized by the presence of two marked seasons, one rainy and another dry, across its 4 regions through the year. Still, certain energy services required in homes may vary depending on their location because of the significant temperature differences among those regions. In the particular case of DHW, according to [1], only 32.2 % of Ecuadorian homes have hot water at their disposal. Presumably, most of those homes are located in the highlands because in the costal, insular and Amazonian regions DHW may not be required since temperature in those territories is relatively high for the most part of the year. Particularly, the city of Cuenca is located in the highlands of Ecuador or the so-called “Sierra”, thus, its altitude is approximately 2.560 meters above the sea level and the average temperature in daytime is around 15°C. Such geographical and climatic characteristics make energy services such as hot water a major necessity for families in there as well as in other cities with the similar conditions which together represent approximately 45% of the population of Ecuador [2]. And to comprehend the preference for certain means to get hot water in those homes and its current costs, it is necessary to make a brief review of the developments of the national energy policy.

The availability of valuable energy resources and principally the state´s model of governance over them may be, to certain extent, deemed as determinants of the patterns of energy consumption in Ecuador. In that country the so-called oil boom started at the beginning of the 70’s when significant reserves of crude oil, specifically in the Amazonian region, were found, extracted and exported, which, along with high international prices for that commodity, provided unprecedented funds to the national government [3]. Supported by those increasing revenues, in 1974 the government passed a scheme of general subventions to basically freeze the prices of energy vectors such as gasolines and LPG which, in that order, have been widely used in transportation and domestic energy services. And even when successive regimes have faced difficulties to cope with the financial burden that those subsidies represent, they have subsisted through the years mainly because of the social unrest that any attempt of reform may trigger [4]. But, although Ecuador has been a net crude oil exporter for decades, it is currently a net importer of oil by-products as its national refining capacity is limited and inconsistent to cover an increasing internal demand for fuels. In the particular case of LPG, the national production covered only a share equivalent to approximately 12% respect to the national demand by 2015, around 20% by 2018, and less than 14% in 2019 [5]. Again, the necessity for the government to keep a reliable supply of LPG, even recurring to imports, is explained by the fact that most of it is required for energy services in homes. By 2019, from a total national demand of approximately 14 million BBL of LPG, near 89% was directed for consumption in homes [6]. Moreover, from the total energy consumption in Ecuadorian households, 13 MBOE by 2020, LPG represented 51.8%, electricity 38,4% and firewood 9.7% [7].

The significant consumption of LPG in the residential sector seen nowadays is mainly employed for cooking and water heating, however, the share of each of those uses is undetermined. Still, steady increments in the national demand for LPG has been observed through the years due in part to the fact that the price of LPG for domestic use, 15 Kg load, has been kept constant since 2001 at $1.60. For instance, 12.7 million BBL were demanded by 2015 nationwide, and increased to approximately 14.9 million BBL in 2021 [5]. And in a business-as-usual scenario, forecasts [i] suggest that by 2030 the annual demand for LPG may reach 17.4 million BBL rising at yearly rate close to 1.8%. The fiscal expenditure in subventions to the prices of hydrocarbons such as diesel, naphtha and LPG for internal consumption came to approximately $28,531 million [ii] between 2007 and 2021 [5]. Comparatively, public spending amounted to about $31,000 million by 2021 [8]. In the particular case of LPG, subsidies added up to nearly $6,080 million during that 15-year period and in 2021 alone came to approximately $517 million [5].

From the social perspective, the distribution of all those resources among different segments of the population proves questionable. [9] analyzed the distributional effects of the energy subsidy scheme on households of Ecuador and concluded that, in absolute terms, resultant benefits are greater for better-off households than for poor ones. Moreover, that study found out that, under the current scheme, it costs $5 to transfer $1 to the bottom income quartile in the case of LPG. The extensive scheme of subventions, granted without distinction among income levels, has provoked a notable shift to technologies working on fuels with subsidized prices [3]. In the particular case of DHW, a noticeable adoption of centralized systems for household water heating in Ecuador started at the beginning of the 90's arguably at the expense of point-of-use electric shower heads. According to figures from [10], imports of GTWH increased particularly since 1994. By 2004 a surge of such imports begun and reached a peak in 2011 to amount $84 million (which is approximately tenfold that of 2001). Afterwards, imports of that type of water heaters have fallen, nevertheless, average approximately $1.25 million per year between 2017 and 2021. Based on those figures, it may be argued that GTWH is a well-known technology and has brought gains in terms of comfort to many homes in the Andean region of Ecuador.

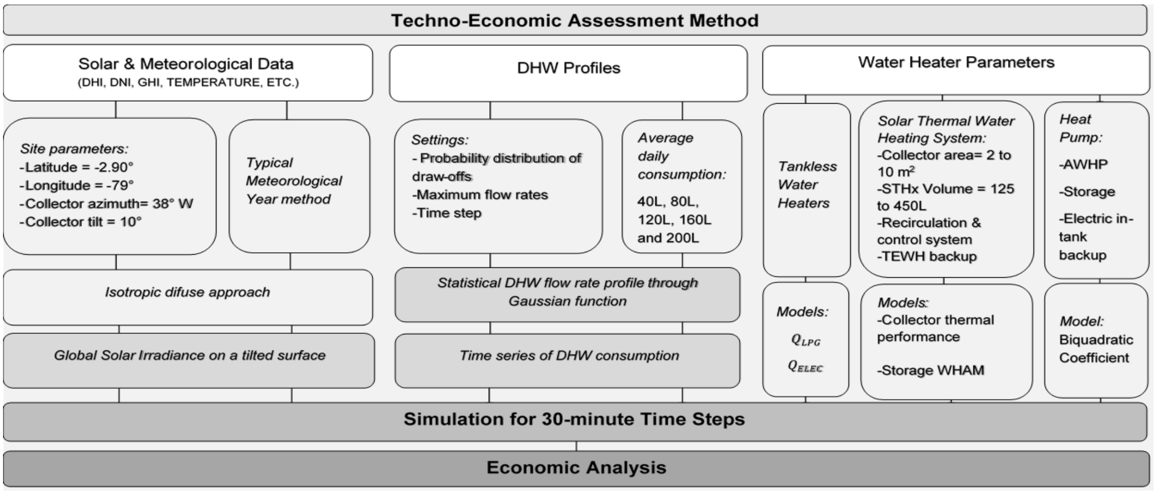

Figure 1. Method for techno-economic assessment

Besides the implications that any subsidy reform may have on energy services like domestic hot water, by now the literature reveals a limited number of studies in this regard in the context of Ecuadorian cities like Cuenca. For instance, under the solar and meteorological conditions of the Andean zones of Ecuador, [11] carried out a quantitative evaluation of thermal and photovoltaic systems accompanied with LPG burning and electric heaters to provide hot water to a home with an occupancy of 4 people. That study concluded that solar thermal systems are more cost effective as they perform with higher efficiency than photovoltaic systems under the stated conditions. Moreover, [12] proposed a numerical and experimental study on solar thermal collectors using weather data gathered in situ in the city of Cuenca. That study determined that for radiation levels of 500 W/m^2 and 712 W/m^2 the experimental thermal efficiency of a solar collector was 48.4% and 58.2%, respectively.

Finally, from the current energy policy concomitant with patterns of energy consumption in Ecuador, particularly regarding fuels, emerge a number of issues in terms of fiscal stability, security of supply, social equity and environmental impacts, which make the discussion about pathways to curb the use of certain energy carriers a relevant matter. Consequently, the aim of this study is to assess the technical and economic feasibility of alternatives to LPG-burning heaters for different levels of DHW demand in the context of one of the most representative towns in the Andean region of Ecuador, the city of Cuenca. The present study circumscribes to determine the performance of heating systems such as ETWH, STWH and HPWH, which are able to provide hot water from a centralized configuration to multiple fixtures in the entirety of a home. The economic analysis includes the costs of generating DHW by means of GTWHs with LPG at subsidized price, which is the current state, and also under a hypothetical liberalization of the price for that fuel. Some incentives that may prompt the adoption the abovementioned alternatives will be explored as well

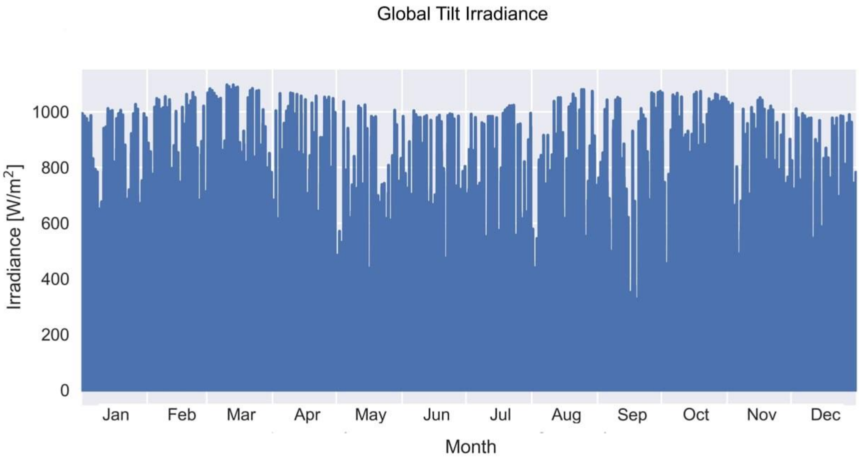

Figure 2. Global Tilt Irradiance in the city of Cuenca.

METHOD

A diagram of the inputs, both data and parameters, and processes required to carry out the proposed assessment is shown in Fig.1.

Solar and meteorological data

The solar and meteorological data, generated from satellite-modeled estimations with a half-hour frequency, for Cuenca is available in the NSRDB [13]. The components of solar radiation in that database are computed by the NREL's Physical Solar Model. According to [14], the data provided by NSRDB varies in average between 5% for global horizontal irradiance and 10% for diffuse horizontal irradiance compared to data from surface measurements. Among the limitations of this type of data it should be noted that it is not available at frequencies lesser to 30 minutes and that it normally represents a geographical area between 3 and 6 square kilometers [15]. Based on the method proposed by [16], data from 1998 to 2020 was used to build a TMY dataset in the form of time series of solar radiation components along with meteorological variables such as temperature, atmospheric pressure, etc. The isotropic diffuse method proposed by [17] and elaborated by [18] was employed to obtain GTI for each time step (Fig. 2). The orientation of the solar collector was set to 38°W, resultant of a series of iterations aiming to maximize GTI. The tilt angle was set to 10° as suggested by [19].

Domestic hot water profiles

To generate sample DHW load profiles, considering average daily consumptions for 40, 80, 120, 160 and 200 liters, the probabilistic method proposed by [20] was used. This approach applies a Gaussian function for calculating the probability of flow rates for each time step. The probabilities for daily drawoffs assume that is likely that high household hot water demand occur in the morning (50%) between 6:30 am and 7:30 am in weekdays.

Water heater parameters

Tankless water heaters

These type of systems, either running on gas or electricity, are also known as instantaneous since they heat up water only at the moment when it is required, therefore, they are deemed as more efficient compared to systems equipped with storage tanks as there are no standby losses. The energy requirements (Q_{LPG}) to provide DHW by means of a GTWH were calculated using Eq. 1 [21].

$$Q_{LPG} = \left[\frac{(V_w \times \rho_w \times \Delta T \times Cp_w)}{3.6e^{+06}\left(\frac{J}{KWh}\right)} \right] / [\eta_{GTWH}] \quad (1)$$

The rated efficiency (η_{GTWH}) was set as constant at 82% even though it may be a function of the daily consumption profile and the intervals of the draw-offs [22]. For the case of the energy demand using a ETWH (Q_{ELEC}) the same equation was applied with a constant rated efficiency (η_{TEWH}) of 98% as stated by [23]. This type of water heaters requires an electric supply that can provide a large amount of electric current, up to 300 amperes, when installed as an in-house centralized system. Such amperages may require upgrades to the standard electric service provided to homes in Cuenca, currently at a maximum of 200 amperes, which would carry costs that are unknown at this point. Therefore, the option of generating DHW by means of ETWHs are considered only for demand levels up to 120 liters per day and assuming that maximum draws of 120 amperes can be supplied for the exclusive operation of the water heater.

Solar thermal water heating system

As shown in Fig. 3, this system is composed of one or more solar collectors, pump, storage tank, backup heater (ETWH) and recirculation pipes. The main criterion for sizing a solar thermal water heating system is the demand for DHW [24]. Therefore, the rated thermal performance of the collector was used as reference for calculating the area required to heat the daily DHW demand for each level of consumption. Then, the capacities of the storage tanks were determined using the rule that states that for one-tank systems for each square feet of collector area there must be at least 1.25 gallons of storage [25]. A summary of the STWH sizes can be seen in Table 1.

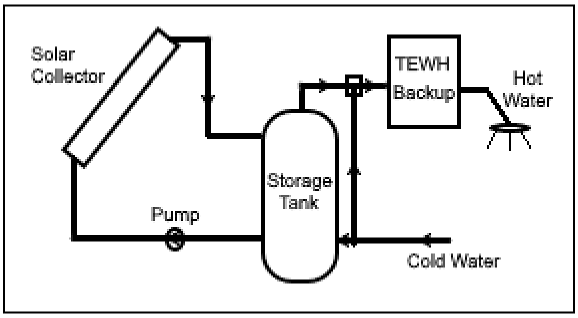

Figure 3. Solar thermal water heating system.

The usable heat gain of the collector was computed based on the approach by [26] and the parameters obtained empirically by [27]. The performance of the STHx was modeled according to the WHAM approach [28]. The simulation process for the whole STWH was carried out based on the MSWH model [29]. The collector efficiency was calculated as the rate between the share of usable heat at the storage inlet, and the mean solar daily tilted irradiation in Cuenca which is approximately 1895 KWh/m2. The STWH system overall efficiency is around 7.8 % and was computed from the heat delivered at the storage tank outlet.

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Table 1. Technical parameters of the solar thermal water heating system

DHW Average Daily Demand	Units	40L	80L	120L	160L	200L
Gross collector area	m²	2	4	6	8	10
Linear heat loss coefficient	W/(m² K)	4.05				
Quadratic heat loss coefficient	W/(m² K²)	0.0073				
Collector zero loss efficiency	%	80.90				
Collector efficiency	%	38.57	38.21	37.87	37.80	37.47
Collector Yield per year	KWh(m²)	731.1	724.2	717.7	716.5	710.2
Storage volume	L	100	150	230	300	455
Recirculation pump power	W	25	35	40	45	50
ETWH rated capacity (backup)	KWh	18.00				

Heat Pump Water Heater

An integrated air-to-water heat pump system was considered as another alternative for DHW in this study. Such system is basically composed by the heat pump itself, storage tank and an in-tank electric resistance heater as backup as presented in Fig. 4. The working principle of integrated air-to-water heat pumps for water heating consist on the use of electricity as energy input to allow a flow of thermal energy, instead of performing a conversion electricity to heat, which make them reach efficiencies that surpass 200% [30]. This implies that for each unit of energy input at least to two units of heat equivalent are obtained. [30] also mention that empirical data proves that the performance of HPWH depends on hot water daily demand volumes and timing as well as on ambient temperature.

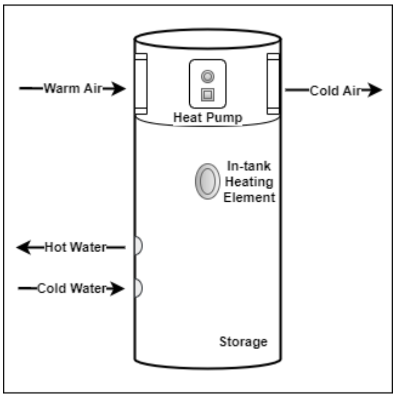

Figure 4. Integrated Air-to-Water Heat Pump.

Consecutive draw-offs and high consumption volumes, respect to the storage capacity, may activate the backup mechanism constantly which will reduce the overall efficiency of the system. Finally, at high ambient temperatures the heat transfer increases which facilitates more efficient water heating. As explained in Tab.2, two storage tank sizes -approximately 220L and 300Lwere considered. The technical parameters were taken from [31]. Sizing for each level of consumption was set according to [32]. The biquadratic coefficients model [33] was employed to calculate the performance of the HPWHs.

Table 2. Technical parameters air-to-water heat pump

DHW Average Daily Demand	Units	40L	80L	120L	160L	200L
Nominal tank capacity	L	220	220	220	302	302
In-tank electric element (backup)	KW	1.5				
Heat pump thermal capacity	KW	1.7				
Maximum power capacity	KW	2.35				
Voltage/Frequency	-	220–240 V / 60/50 Hz				
Rated Coefficient of Performance (COP)	-	3.05	3.05	3.05	3.39	3.39

Economic assessment

A detailed cost analysis was carried out aiming to determine unit prices to expose the current situation and the rates of alternatives. A categorization of three main types of costs is provided in Tab. 3; investment in the equipment, maintenance costs and operation costs generated by energy requirements. The typical lifetime of the different water heating technologies was set according to [22]. To obtain the annual total cost for each of the alternatives a discount rate of 6%, similar to the deposit interest rate in Ecuador [34], was assumed.

For the case of the GTWH, two fuel prices were considered; the current subsidized LPG price at $ 1.60 and the price without subsidies at $14.26 by July 2022 [35]. On the other hand, the price of electricity was set at $0.105 KWh which is a fixed rate for domestic use in Ecuador. Pumps required for forced-circulation STWH systems were quoted by [37]. The prices for solar collectors come from [38]. Considering that the present study focuses on systems able to provide in-house centralized DHW, it was assumed that the water connections required for such service were already in place. The availability of electricity supply of 220 Volts is not common in homes of Cuenca, therefore, approximate costs of displaying one point for that voltage were include for ETWH, STWH and HPWH analysis.

Table 3. Cost breakdown for each alternative

		Daily DHW Demand				
		40L	80L	120L	160L	200L
LPG Tankless Water Heater						
Investments						
Water heater	$	400	500	500	600	600
LPG bottle + accessories	$	70	70	70	70	70
Installation	$	50	50	50	50	50
Total	$	570	670	670	770	770
Technical life	years	20	20	20	20	20
Annual investment	$/year	45.34	54.05	54.05	62.77	62.77
Maintenance costs	$/year	50	50	50	50	50
Fuel costs						
LPG cost at subsidized price	$/year	6.70	13.05	19.11	24.92	30.41
LPG cost at actual price	$/year	95.54	186.08	272.46	355.29	433.65
Total cost subsidized	$/year	102.04	117.11	123.16	137.69	143.19
Total cost no-subsidies	$/year	190.88	290.13	376.52	468.07	546.42
Electric Tankless Water Heater						
Investments						
Water heater	$	600	600	750	-	-
Wiring 220V	$	310	310	475	-	-
Installation	$	250	250	250	-	-
Total	$	1160	1160	1475	-	-
Technical life	years	20	20	20	-	-
Annual investment	$/year	101.13	101.13	128.60	-	-
Maintenance costs	$/year	50	50	50	-	-
Electricity cost	$/year	64.73	129.21	203.50	-	-
Total cost	$/year	215.9	280.3	382.1	-	-
Solar Thermal Water Heating System						
Investment						
Collector	$	800	1600	2400	3200	4000
Storage	$	800	900	1050	1150	1250
Pump	$	300	300	300	300	300
Installation & Piping	$	300	350	400	450	500
Backup system (220V included)		1160	1160	1160	1160	1160
Overall solar system	$	3360	4310	5310	6260	7210
Annual investment	$/year	284.22	367.05	454.23	537.06	619.88
Maintenance costs	$/year	50.00	60.00	70.00	80.00	90.00
Electricity costs	$/year	18.18	25.28	30.06	34.23	37.31
Total cost	$/year	352.41	452.33	554.29	651.29	747.19
Air-to-Water Heat Pump						
Investments						
Integrated Heat Pump	$	2800	2800	3200	3200	3200
Wiring 220V, installation	$	312	312	312	312	312
Total	$	3112	3112	3512	3512	3512
Technical life	years	13	13	13	13	13
Annual investment	$/year	354.13	354.13	399.31	399.31	399.31
Maintenance costs	$/year	50	50	50	50	50
Electricity cost	$/year	164.4	215.6	244.2	278.4	308.8
Total cost	$/year	568.58	619.69	693.49	727.72	758.17

RESULTS AND DISCUSSION

The results of the costing procedure in terms of units of energy is shown in Tab. 4. The analysis of alternatives is conducted considering the current cost of DHW by means of GTWHs with subsided fuel as base case. A noticeable outcome is that the cost of heating water, per-unit of consumption, for a household demanding 40L a day (0.17 $/KWh) is more than three times higher than those demanding 200L (0.05 $/KWh) mainly due to the relatively small difference in the cost of the heaters used in each case. In the

GTWH case, a potential cut of subsidies is analyzed only in terms of the cost of DHW. The assessment of the effects of such measure on the economics of households goes beyond the scope of this study but has been examined by [9].

Table 4. Summary of Water Heating Costs

		Daily DHW Demand				
		40L	80L	120L	160L	200L
Heat demand	GJ/year	2.14	4.28	6.42	8.57	10.70
	KWh/year	595.5	1188.8	1783.0	2380.4	2972.8
LPG Tankless Water Heating subsidized (GTWH-S)	$/GJ	47.60	27.36	19.19	16.07	13.38
	$/KWh	0.17	0.10	0.07	0.06	0.05
LPG Tankless Water Heating no-subsidies (GTWH)	$/GJ	89.04	67.79	58.66	54.62	51.06
	$/KWh	0.32	0.24	0.21	0.20	0.18
Electric Tankless Water Heater (ETWH)	$/GJ	100.69	65.51	59.53	-	-
	S/KWh	0.36	0.24	0.21	-	-
Solar Thermal Water Heating System (STWH)	$/GJ	164.38	105.70	86.35	76.00	69.82
	$/KWh	0.59	0.38	0.31	0.27	0.25
Air-to-Water Heat Pump (HPWH)	$/GJ	264.01	144.20	107.63	84.62	70.60
	$/KWh	0.95	0.52	0.39	0.31	0.26

Estimations in the no-subsidies scenario reveal that costs would significantly increase for higher levels of DHW consumption, more than threefold for 120L, 160L and 200L, compared to the base case. However, costs for low levels of consumption are still higher in absolute terms. The cost analysis also shows that even if subsidies were cut, using a GTWH would provide cheaper DHW than STWH or HPWH. For relatively low levels of consumption, particularly 80L and 120L, ETWHs match the costs to those of the no-subsidies scenario.

Further measures to effect the transition from LPG-burning water heating to more sustainable alternatives can be explored either from the point of view of the costs of GTWHs or the economic incentives for the market implementation of alternatives. Regarding disincentives, in Ecuador there are precedents about the application of taxes directed to LPG-burning equipment. Between 2015 and mid-2018 the government imposed taxes that provoked high increments, about 100%, in the purchase prices of LPG burning stoves and tankless water heaters [39]. Reinstating such taxation over tankless gas water heaters (GTWH-T), annualized costs would increase between twofold and fourfold among the various levels of DHW consumption as can be seen in Tab. 5. Yet such measure applied alone may not be enough to spur a transition from a well-known technology, GTWH, to alternatives that are still more costly. Thus, other measures that may prompt the adoption of the proposed alternatives are examined next.

Table 5. Summary of Water Heating Costs With Different Incentives

		Daily DHW Demand				
		40L	80L	120L	160L	200L
LPG Tankless Water Heating (GTWH-T)	$/GJ	105.30	77.98	65.45	60.73	55.95
	S/KWh	0.38	0.28	0.24	0.22	0.20
Electric Tankless Water Heater (ETWH-S)	$/GJ	91.63	56.45	48.96	-	-
	S/KWh	0.34	0.21	0.19	-	-
Solar Thermal Water Heating System (STWH-R)	$/GJ	132.09	84.72	68.91	60.59	55.62
	$/KWh	0.48	0.30	0.25	0.22	0.20
Air-to-Water Heat Pump (HPWH-R)	$/GJ	234.07	126.81	92.95	67.45	56.18
	$/KWh	0.84	0.46	0.33	0.24	0.20

In Ecuador there are antecedents on the application of subsidized electricity tariffs for certain uses. That has been the case of electric cars that can be charged at an average rate of $0.08/KWh [40]. If a similar price was granted for DHW, cost of electric tankless water heating (ETWH-S) would drop between 5% and 11% making them a cheaper option compared to GTWH-S for levels between 40L and 120L. Moreover, with cheaper electricity, the cost of DHW by means of a heat pump (HPWH-S) would drop 9% and 11% per KWh for 160L and 200L respectively. One aspect to consider is that even when HPWHs may not been the best option cost-wise, in terms of space availability it may be the most suitable option compared to STWH systems. However, for HPWHs to be adopted massively for those levels of consumption, further incentives would be required.

High investment costs make STHW and HPWH systems too pricy for levels between 40L and 120L. On the other hand, considering a scenario of unsubsidized LPG along with taxed GTWHs, solar thermal systems and heat pump water heaters may be competitive for levels of consumption of 160L and 200L if the purchases of collectors, storage tanks, heat pumps were subject of rebates. That is the case of scenarios STWH-R, HPWH-R, which were computed assuming rebates around 30% to the final prices of the equipment. Nevertheless, this kind of incentives is not usual in Ecuador and may be complex to implement because it need to be carefully targeted to homes with high levels of DHW consumption and would need help to cope with the costs of DHW. It is evident that a major challenge when designing incentives or even disincentives for curbing the use of LPG-burning water heating is handling the appearance of benefits of scale. This is because neither the capital costs or operation costs are significantly high among levels of consumption, particularly in the case of tankless water heaters, which, for instance, make costs for 40L comparatively the highest in a per KWh basis.

CONCLUSION

The consequences of the long-lasting and undiscriminating scheme of subsides to the prices of fuels used daily in homes pose serious challenges for the energy policy in Ecuador. Yet, the necessity of curbing the use of those energy carriers, particularly LPG, seems to be unquestionable for several reasons. In terms of security of supply, it is evident that Ecuador needs to curb the widespread use of a fuel, LPG, that is mostly imported due the risks derived of the volatility of international oil markets and the latent occurrence of geopolitical issues affecting the trade of energy carriers.

In the fiscal side, there is no even a correspondence between the income generated by the exports of crude oil, nowadays affected by a stagnant production, and a need for more funds to cover subsidies due to an increasing demand for fuels. Thus, subsidies turn to be a gush in the finances of a government that struggles to generate enough income to cover the public spending.

In the social side, subsidies in Ecuador, to LPG prices in particular, seems to be more favorable for homes with higher demands of energy and capable to afford equipment to obtain services such as DHW. Those homes may not essentially be part of the segments of the population that need governmental support the most. Thus, the current energy policy, regarding fuel prices principally, fails to effect a just distribution of the income generated by the exploitation of national resources and rather deprives financial means to cope with other legitimate social demands.

From the environmental point of view, it is clear Ecuador needs to define paths to decarbonized energy consumption to align itself with international efforts to deaccelerate global warming. In sum, the most import challenge for energy policy in Ecuador at this point in time seems to be about encouraging a new culture on the whole population about energy consumption and its actual costs.

The present study reveals that the adoption of alternative technologies for DHW in Andean cities of Ecuador, such as Cuenca, may not come easily as they may require changes in the way homes consume DHW, principally, in case of using heat accumulators. Besides, there is a latent risk of losing certain gains of wellbeing at the household level brought by a sustained adoption of in-house centralized water heating systems, originated mainly by the oasis of cheap fossil fuels in Ecuador. What is more, it stresses the need to assess the potential lack of financial capacity to afford the costs of those energy services when facing international fuel prices. Therefore, the long-held discussion about targeting subsidies to those who need them the most should be extended to measures, e.g. in the form of rebates or tax breaks, able to encourage the development of markets for water heating equipment that can make them competitive compared to those running on LPG. Finally, this study remarks the necessity for further empirical research on the DHW problem in Andean cities of Ecuador.

Notes

i Forecasts performed by means of an additive Holt-Winters model.

ii Calculated as the difference between costs and revenues from the internal commercialization of oil by-products.

Nomenclature

BBL	Oilfield Barrel [42 U.S. gallons]
MBOE	Millions of Barrels of Oil Equivalent
DHW	Domestic Hot Water
NREL	U.S. National Renewable Energy Laboratory
NSRDB	National Solar Resource Data Base
STWH	Solar Thermal Water Heating System
MSWH	Multiscale Solar Water Heating model
LPG	Liquefied petroleum gas
GTWH	LPG Tankless Water Heater
GTWH-S	LPG Tankless Water Heater along Subsidized Fuel Price
ETWH	Electric Tankless Water Heater
HPWH	Air-Source Heat Pump Water Heating System
L	Liters
40L	40 liters DHW average daily demand
80L	80 liters DHW average daily demand
120L	120 liters DHW average daily demand
160L	160 liters DHW average daily demand
200L	200 liters DHW average daily demand
m2	Square meters
COP	Heat pump rated coefficient of performance
GTI	Global solar irradiance on a tilted surface [W/m2]
ηGTWH	Rated GTWH efficiency
ηETWH	Rated ETWH efficiency
TMY	Typical Meteorological Year
STHx	Solar thermal tank equipped with heat exchanger
QLPG	Total energy consumption GTWH [KWh/year]
ρw	Density of water [1 Kg/L]
ΔT	Temperature Outlet-Inlet difference [°C]

Cpw	Specific heat of water [4180 J/Kg °C]
GJ	Giga joules
$	U.S. Dollars

CONFLICTS OF INTEREST STATEMENT

Cristian Campoverde-Prieto declares no conflicts of interest.

CONTRIBUTION OF THE ARTICLE IN THE LINE OF RESEARCH

This case study contributes to set the stage for discussing the viability more sustainable alternatives for domestic water heating in the context of the Andean city of Cuenca.

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