PROSPECTIVE FEASIBILITY ASSESSMENT OF INSTALLING SOLAR WATER HEATERS IN HOUSEHOLDS AS AN ALTERNATIVE FORM OF USING LPG IN IMBABURA- ECUADOR

EVALUACIÓN PROSPECTIVA DE LA VIABILIDAD DE LA INSTALACIÓN DE CALENTADORES DE AGUA SOLAR EN LOS HOGARES COMO UNA FORMA ALTERNATIVA DE USO DE GLP EN IMBABURA, ECUADOR

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ABSTRACT

Ecuador is a country with energy needs, which should be efficiently met by means of technical and financial considerations. Existing policy promotes the change of the national energy mix to renewables. In this context, this policy will discourage the consumption of liquefied petroleum gas (LPG) by eliminating gradually its subsidy. Therefore, this research carries out a prospective analysis up to 2050 in order to determine the feasibility of installing solar water heaters as alternative to the conventional systems based on LPG and firewood. In the same sense, this paper includes: the determination of the solar energy potential of Peguche (a community located in Imbabura, Ecuador), trends of the solar system's costs, and trends of oil prices and oil sub-products for three prospective scenarios. In order to evaluate the feasibility of the project, the payback period based on the savings in the fuel consumption is calculated. To conclude, the paper highlights the environmental advantages in the use of this renewable energy in terms of greenhouse gas emissions (GHG).

KEYWORDS
Solar heating water, LPG and solar energy, solar energy prospective, future prices of oil and sub-products, prospective costs of solar thermal collectors.

RESUMEN

Ecuador es un país con necesidades energéticas, que debe ser cubierto eficientemente por medio de consideraciones técnicas y financieras. La política existente promueve el cambio de la combinación energética nacional a las energías renovables. En este contexto, esta política desalentará el consumo de gas licuado de petróleo (GLP) eliminando gradualmente su subvención. Por lo tanto, esta investigación lleva a cabo un análisis prospectivo hasta el año 2050 para determinar la factibilidad de instalar calentadores de agua solares como alternativa a los sistemas convencionales basados en GLP y leña. En el mismo sentido, este trabajo incluye: la determinación del potencial de energía solar de Peguche (una comunidad ubicada en Imbabura, Ecuador), las tendencias de los costos de sistemas solares y las tendencias de los precios del petróleo y subproductos de petróleo para tres escenarios prospectivos. Para evaluar la factibilidad del proyecto, se calcula el período de amortización basado en los

Fecha de recepción: 31 de mayo de 2016.
Fecha de evaluación: 29 de junio de 2016.
Fecha de aceptación: 2 de agosto de 2016.

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ahorros en el consumo de combustible. Para concluir, el documento destaca las ventajas ambientales en el uso de esta energía renovable en términos de emisiones de gases de efecto invernadero (GEI).

PALABRAS CLAVE
Agua de calefacción solar, GLP y energía solar, prospectiva de energía solar, precios futuros de petróleo y subproductos, costes potenciales de colectores solares térmicosos

NOTATION

Table N° 1. Notations to perform equations

Notation	Description
L	Water loads
Lw	Sensible heat of water
Lt	Heat losses in tank
$\dot{m}$	Mass flow of water
Cp	Specific heat of water
ta	Input average temperature of water
to	Output temperature of water
(UA)t	Coefficient of heat losses of the tank
K	Thermal conductivity of material
At	Area of the tank
S	Thickness of the walls
tt	Average temperature inside the tank
$\dot{m}_{LPG}$	Flow of LPG

1. INTRODUCTION

The 6.8% of the population in Ecuador does not count on electricity supply (INEC, 2010); therefore, the source of hot water in those households is unavailable or restricted to heating either with LPG or firewood.

For a better approach of this research, it is worth mentioning that the Government of Ecuador subsidies the fossil fuels and electricity that people and industry consume. Only for LPG in 2012, Ecuador would have spent USD 710'949.570 as subsidy (CELEC EP, 2014); therefore, it is a foremost policy to promote the use of free and renewable sources of energy, so that those economical resources can be intended for other social projects.

According to Banco Central del Ecuador the Price of LPG traded in the country is 0.098 USD/kg without taxes, but included the government subsidy. Therefore, the final price that people pay for a 15 kg cylinder is 1.60 USD (Banco Central del Ecuador, 2009); this is the lowest price in the region. Ecuador does not produce enough LPG to supply the internal demand and the percentage of importation is close to 80%. (ARCONEL, 2013)

This valuation takes into consideration two key facts. Firstly, The National Government is fostering the forgoing of LPG by means of the gradual elimination of the subsidy (ARCONEL, 2013). Secondly, the use of firewood to heat up water involves logistic difficulties and respiratory illnesses as side effects among the people who handle it.

Given the complexity of the energy market in Ecuador, this study intends to describe the prospective scenarios of installing solar heaters, taking into consideration the most important variables that will shape the market in the future. It is reasonable to suggest that an improvement in technology and production methods of solar systems accompanied by an increase in fossil fuels will promote the investments in solar.

In order to sustain the precedent suggestion it is necessary to determine the technical and financial feasibility of installing solar heaters in prospective scenarios. The former analysis covers the solar energy calculations and thermodynamics concerns whilst the latter analysis considers the payback period of the investment according to the year when the system is installed.

Section 1 describes all the geographical features and heat water consumption patterns, which outline the solar heater systems according to the methodology of Duffie and Beckam. Section 2 collects all necessary information of solar devices, water requirements, and LPG properties, which will be used like inputs variable to design the model. Calculations will be carried out in Section 3 including the technical determination of the solar potential and financial study. Section 4 shows the outcomes of the prospective until 2050 including the costs of the technology, future prices of LPG, and payback periods for optimistic and pessimistic scenarios. Finally, Section 5 comprehends the conclusions and recommendations of the research and how much a variable can influence on the accomplishment of the project. The outcome demonstrates that the payback period and consequently the feasibility of installing solar heaters in Ecuador depend greatly on the presence of subsidies and in a lesser extent on the future costs of the technology.

2. DEVELOPMENT OF THE PROJECT

The selected zone to carry out the study is Peguche, which is a rural community located in Otavalo, Province of Imbabura at the northern highland of Ecuador. In Imbabura, 10% of the population still uses firewood for cooking and 3% of population does not have access to electricity. Moreover, only 62.9% of the households count on shower for sole use, which means that almost one third of people, in that zone, has either to share the shower or to heat up water with LPG or firewood. (INEC, 2014). This community has a significant solar potential as it can be seen at Figure 1

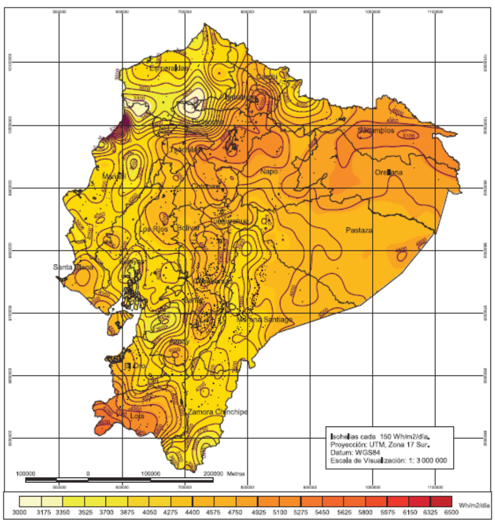

Figure 1 Ecuador Solar Map represents the solar potential per region; it shows that Peguche is located in Imbabura. The darker the zone in the map is the better solar potential is as well (CONELEC, 2008).

Within the framework of the technical considerations, it is defined both the geographical coordinates of Peguche: latitude 0.244386, longitude -78.251390 (NASA, 2015) and the design parameters which are specified according with the method of Duffie and Beckam.

Water average consumption is 60 liters per person per day which includes hot water for shower and sinks of both toilet and kitchen. Each family is composed by 4 members and the temperature of the hot water to be consumed is 45°C. The slope is close to the latitude of the zone and the floor is uniform (Jhon A Duffe, 2013). In theory, the slope and latitude are close values in order to obtain good results of energy uptake.

The meteorological information is provided by National Aeronautics and Space Administration (NASA, 2015). The main structure includes a collector of evacuated tubes, storage tank and controller; altogether coupled in a thermo siphon system.

In order to carry out the financial comparison, the study includes the operation of an alternative system driven with LPG. In that sense, no LPG subsidy from 2020 and henceforth is assumed. To perform the prospective of financial feasibility, the study contemplates 3 scenarios of future oil prices in global market until 2050, according to IEA "Energy Technology Perspectives 2DS, 4DS y 6DS", (International Energy Agency, 2015).

Moreover it is considered the prospective range of prices of solar systems in future for optimistic and pessimistic scenarios, so that an integral analysis can be undertaken.

Once the size of the solar collectors is determined it will be possible to establish the upper and lower range of prices for that system. Then those values will be related with the DS scenarios to determinate the payback period of investing in solar heaters for each prospective year.

Finally the results will provide information of how feasible is to install a domestic solar heater over time in Ecuadorean energy market, taking into consideration the change of payback periods for each year.

3. DATA AND DESIGN PARAMETERS

3.1 COLLECTOR

The outcome of the study depends on both the design parameters and equipment selected. In this case, the option is a solar heater system offered in local market, called local FKT-1s Portrait of TECNOVA with storage tank. (Bosch Thermotechnology Corp, 2011).

Table N° 2 Parameters of the Collector

Transmittance	92%
Absorbance	96%
Efficiency η0 (%)	85%
Net area of collector [m^2]	2.25
K1 [W/m^2]	4.04
K2 [W/m^2][1]	0.01

Source: (Bosch Thermotechnology Corp, 2011)

[1](Effective heat transfer coefficient, useful to design the system, it depends on the configuration and materials of each device.)

Table N° 3 Physicochemical properties of water

Density of water [kg/m^3]	1000
Specific heat of water [kJ/kg K]	4.19

Source: (Çengel, 2011)

3.2 STORAGE TANK

The performance of the system relies on the stratification capacity, insulation level and coupling of the tank with the collector.

Table N° 4 Parameters of the tank

Insulation material	Polyurethane
Wall thickness [m]	0.05
Thermal conductivity [W/m C]	0.03
Radio [m]	0.29
Area [m2]	1.05
Longitude [m]	0.28
Volume [m3]	0.15

Source: (Bosch Thermotechnology Corp, 2011)

3.3 LPG SYSTEM

The payback method is defined as the time, usually expressed in years, it takes for the cash income from a capital investment project to equal the initial cost of the investment. (Small Business, 2015) In energy projects payback time is a function of annual heat utilized per USD invested and fuel cost. (Gunthrie, 2015). Consequently, it is necessary to determine the fuel consumption.

Table N° 5 Physicochemical properties of LPG

Fuel: LPG	
Propane LHV [kJ/kg]	46340
Butane LHV [kJ/kg]	45370
Calorific Value of LPG [kJ/kg]	45855
Mass of gas per cylinder [kg][2]	15.00

Source: (Çengel, 2011), (INEN, 1998)

[2](It is the typical LPG cylinder traded in Ecuador according to the national normative NTE INEN 111:1998)

Both system, solar and LPG, need potable water supply suitable for human consumption with an inlet pressure of at least 5 bar, because no electric pumping is considered, due to the study focuses on zones without access to electricity grid.

3.4 EMISSION FACTORS

In order to shows the environmental advantage of using solar heaters instead of LPG, the green gashouse emissions that would not be released to atmosphere are calculated. IPCC Guidelines is used to estimate those emissions. (IPCC, 2006)

Table N° 6 Emission Factors of GLP

Fuel: LPG	C02	CH4	N2O
Emission factors [kg/TJ]	63100	1	0,10
Equivalent factors [kg CO2 eq]	1	21	310

Source: (IPCC, 2006)

4. CALCULATIONS

4.1 SPECIFY ENERGY AVAILABLE

The energy consumption and the size of the system are drawn up from the meteorological conditions of Peguche, which are shown in Table N° 7. In that way, the offer of available energy

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-solar radiation- and the demand of required energy -latent heat of water- can be determined.

4.2 SYSTEM CALCULATION

To modelling and sizing the system, it is used the method "F Chart of Centro Integrado FP Superior de Energías Renovables 2004 Gobierno de Navarra". The system calculates the quantity of produced energy and the number of required modules to meet the demand of hot water, based on the design variables mentioned in Section 3.

Table N° 7 Meteorological Conditions of Peguche[3]

Month	Radiation[1] [Wh/m2/day]	Temperature Average [C]	Temperature Minimum [C]	Temperature Maximum [C]
January	3960,0	19,9	17,3	22,6
February	4090,0	20,3	17,6	23,2
March	4340,0	20,6	17,7	23,8
April	4170,0	20,9	18,0	24,2
May	3910,0	21,2	18,0	24,8
June	3800,0	21,0	17,6	24,8
July	4030,0	21,1	17,2	25,4
August	4050,0	21,9	17,6	26,5
September	3880,0	22,0	18,2	26,1
October	3860,0	21,3	18,2	24,8
November	3740,0	20,3	17,7	23,3
December	3690,0	19,9	17,6	22,5

Source: (NASA, 2015).

[3](The conditions are evaluated for latitude of 0,244386. Solar radiation and temperature data correspond to average values per month)

4.3 COLLECTOR AREA

The effective area is defined like the useful surface exposed to solar radiation. The energy supplied by the system and the area required for the modules is equals to 2333 [kWh/year] and 4.50m^2 respectively. This area corresponds to 2 modules with an average efficiency of 36%. The relationship between the number of panels and persons is 1.13 [m^2/person]. All those outcomes are obtained by the software.

4.4 LPG HEATING SYSTEM.

The required consumption of LPG, which is equivalent to the useful solar energy, is calculated on basis of the hot water demand or water loads L.

$$L = L_w + L_t \quad (1)$$

$$L_w = \dot{m}Cp(t_o - t_a) \quad (2)$$

The flow of water is calculated with the product of the number of persons at each home, the average consumption of water per person and the water density. Heat losses in the tank is calculated with equation (3)

$$L_t = (UA)_t(t_t - t_a) = \frac{k}{s}A_t(t_t - t_a) \quad (3)$$

Firstly, it is calculated the water loads for each month and then all those results are added up to obtain the annual loads. Once the annual water loads are obtained, it is possible to determine the quantity of LPG required.

$$\dot{m}_{LPG} = \frac{L_w + L_t}{\text{Net Calorific Value of LPG}} \quad (4)$$

In order to calculate the sensible heat needed to supply hot water with LPG it is maintained both considerations: 4 persons per family and a consumption of 60 liters per person per day according to Duffie and Beckam. The outcome is 192.96 kg of LPG that corresponds to 12.86 cylinders of 15kg per year.

4.5 FINANCIAL ANALYSIS

Table N° 8 indicates the future prices of petroleum until 2050, wherewith the prospective scenarios are created. "It takes account of broad policy commitments and plans that have been announced by countries, including national pledges to reduce greenhouse-gas emissions and plans to phase out fossil-energy subsidies" (International Energy Agency, 2015)

Table N° 8 Prospective scenarios of petroleum prices

Year	2DS	4DS	6DS
2015	50,5	50,5	50,5
2020	105,0	112,0	116,0
2025	104,0	118,0	128,0
2030	102,0	123,0	139,0
2035	101,0	128,0	147,0
2040	100,0	132,0	155,0
2045	99,0	135,0	161,0
2050	98,0	137,0	167,0

Source: (International Energy Agency, 2015)

Other important issue to consider is the prospective price in solar technology, because this fact also determinates how attractive to install solar heaters in future is. In this regard, Figure 2 shows upper and lower range of prices, according to prominent energy research institutes.

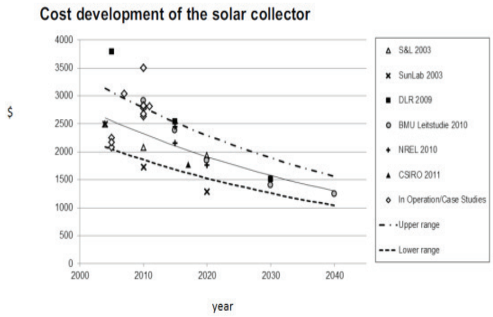

Figure 2 Prospective of solar heaters collectors until 2040 that enables the calculation of future prices of solar system from the trend behavior (Telsnig, Eltrop, Winkler, & Fahl, 2013).

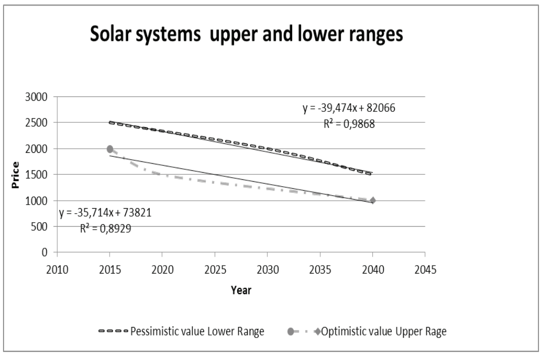

Figure 3 Optimistic and pessimistic scenarios of prices in solar technology, lineal regressions enable to obtain trend prices for each year.

Improving production methods and consumption preferences, determinate an optimistic scenario with a range of prices from USD 2000 to USD 1000 per system for 2015 and 2040 respectively. In the same way, a possible shrink of production and preferences in solar determinate a pessimistic scenario with range of prices from USD 2500 to USD 1500 per system for 2015 and 2040 respectively.

Finally, the payback period (t) of investing in the solar system on basis of fuel savings is estimated (Berk, 2014).

$$t = \frac{\text{Initial investment}}{\text{Fuel savings per year}} \qquad (5)$$

In summary, this study compares the prices of 3 prospective scenarios of fossil fuels with 2 prospective scenarios of solar technology.

4.6 COMPARISON OF PROSPECTIVE PRICES OF LPG

This study considers 3 prospective prices of LPG based on the behavior of petroleum in the future, by means of ordinary least squares method with the simple assumption that the basic relationship between petroleum prices, and sub-products observed in time have a proportional response each other. Nevertheless it is important to compare the results in this model with the projections of LPG in international markets to show that the calculations are aligned with reasonable trends. In this sense IEA launched projections of petroleum products prices up to 2040. LPG is expresses as both fuel liquid prices and as energy prices for residential sector Figure 4 shows the relationships and trends.

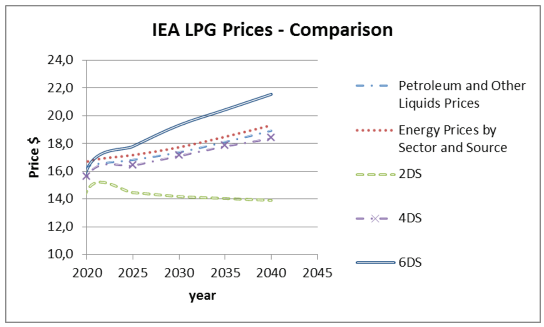

Figure 4 International projections and calculations of LPG prices. This figure contains the trends of LPG prices calculated for this model in scenarios 6DS, 4DS, and 2DS and also the forecast of IEA of LPG prices in future. (IEA, 2015) [Own modification]

4.7 GREEN GASHOUSE EMISSIONS

The inventory of green gashouse emissions of Ecuador includes CO_2, CH_4 and N_2O like the pollutants of most significance. For this study that assumption is conserved and the method of calculation is described by "IPCC Guidelines and its CO2 equivalent factors".

The energy output is multiplied times each specific emission factor of LPG. Then those values should be transformed to CO2 equivalent by means of equivalent factor.

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$$CO_{2equivalent} = \sum_i^n HLV \times \dot{m}_{LPG} \times Emission\ factor \times Equivalent\ factor \quad (6)$$

5. RESULTS

5.1 SOLAR HEATER SYSTEM

The outcome of the calculations, obtained with the model F-Chart, has the following specifications:

Thermo siphon system FKT 1-s
Number of modules: 2
Collector area [m2]: 4.50
Total consumption of water per day [240 l/d]
Total met demand by the solar system [%]: 94.90
Total energy produced per year [kWh/year]: 2333
Total shortage of energy per year [kWh/year]: 126

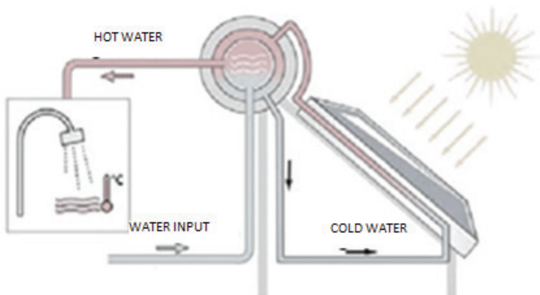

Figure 5 Thermo siphon heating system, it represents the scheme of the heater installed on a rooftop of a typical household. The slope varies according to the latitude (Bosch Storage Technology, 2011) [Own modification]

5.2 HEATING SYSTEM DRIVEN WITH LPG

According to the loads analysis in Section 3.4, this system requires 12.86 cylinders of LPG of 15kg per year.

5.3 FINANCIAL STUDY

In this section the results are sorted by the prices of solar systems, so that the influence of each variable can be contrasted.

Table N° 9 Payback periods of solar system

Year	Pessimistic Scenario (years)			Optimistic Scenario (years)		
	2DS	4DS	6DS	2DS	4DS	6DS
2015	122,72	122,72	122,72	90,23	90,23	90,23
2020	12,40	11,62	11,22	8,94	8,38	8,09
2025	11,46	10,10	9,31	8,06	7,11	6,55
2030	10,60	8,79	7,78	7,24	6,01	5,32
2035	9,61	7,58	6,60	6,33	4,99	4,35
2040	8,60	6,52	5,55	5,39	4,08	3,48
2045	7,58	5,56	4,66	4,44	3,25	2,73
2050	6,53	4,67	3,83	3,46	2,48	2,03

Source: Author

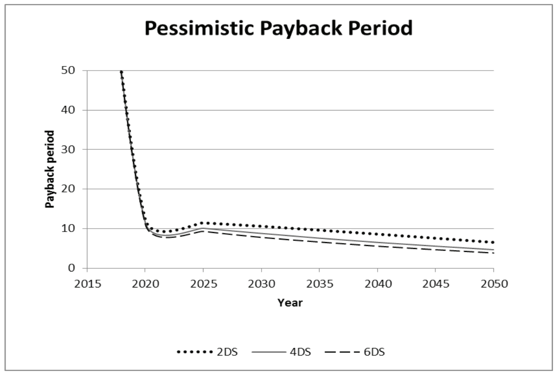

Figure 6 represents high prices of solar technology compared with 3 scenarios of LPG. Since 2020 the payback period decreases greatly due to the retirement of subsidy.

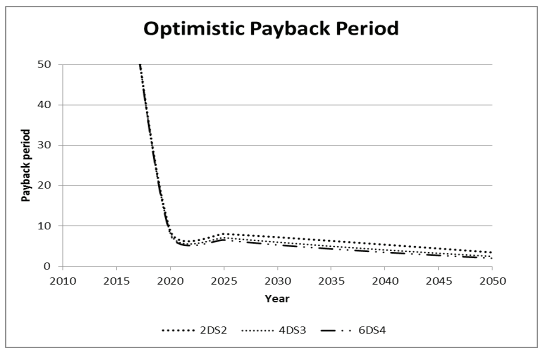

Figure 7 represents low prices of solar technology compared with 3 scenarios of LPG. Since 2020 the payback period decreases greatly due to the retirement of subsidy.

5.4 COMPARISON OF PROSPECTIVE PRICES OF LPG

Figure 4 and Table N° 10 mirror that projections in all scenarios and in the IEA models have increasing trends

Table N° 10 Projections and comparison of LPG prices

year	LPG Prices[4]	Energy Prices[5]	2DS	4DS	6DS
2015	14,9	15,2	1,6	1,6	1,6
2020	16,4	16,7	14,6	15,6	16,1
2025	16,8	17,2	14,5	16,4	17,8
2030	17,4	17,7	14,2	17,1	19,3
2035	18,1	18,5	14,0	17,8	20,4
2040	18,9	19,3	13,9	18,4	21,6

[4] (Petroleum and Other Liquids Prices)

[5] (Energy Prices by Sector and Source)

5.5 GREENHOUSE GAS EMISSIONS

Regarding with the emissions, results are presented in kilograms of CO2 equivalent. The overall balance corresponds to 558.81 kg of CO2 equivalent and this value represents the greenhouse gas emissions rereleased to the atmosphere per family.

Table N° 11 CO2 equivalent emissions

FUEL	GASES		
LPG	CO2	CH4	N2O
Total emissions	558,35	0,01	0,00
Equivalent CO2 emissions	558,35	0,19	0,27
Total equivalent CO2 emissions		558,81	

6. CONCLUSION

Prospective scenarios have different results according to both the oil future prices in 3 different scenarios and decreasing costs of solar technology for upper and lower levels. Because solar and LPG are considered substitute goods, high demand of petroleum and sub-products in future has a positive influence in the cost of solar technology, which encourages the use and implementation of the latter.

Figure 6 and Figure 7 mirror the behavior and influence of fuel prices, solar heaters technology systems, and subsidies from 2015 to 2050. By 2050, the payback period for 6DS goes from 3.83 to 2.03 years according to the cost of technology. Those results represent the total range of time in very optimistic and pessimistic conditions respectively as long as the demand and prices of oil in future increases; therefore favorable conditions for solar systems can improve the payback period up to 53%.

Results indicate very high payback periods since 2015 to 2020, due to the subsidy of LPG. In the same way, Table N° 12 shows the percentage of subsidy until 2015. It is worth mentioning that this value changes annually according to international prices of oil.

Table N° 12 Percentage of Subsidy of LPG

year	Oil price $/b	LPG price $/c	% Subsidy
2010	79,48	11,50	86%
2011	94,88	14,62	89%
2012	94,05	13,31	88%
2013	97,98	12,79	87%
2014	93,26	12,20	87%
2015	50,46	6,84	77%

Source: (Ministerio de Hidrocarburos, 2015) [Own modification]

The subsidy performs an important role in determining the feasibility of installing solar systems to such an extent that no difference can be seen in any scenario during 2015 to 2020. Therefore the retreat of the subsidy has more influence than prospective future prices of petroleum and technology.

The fostering of local production as well as the development of internal policies, within the framework of importations and tariff preferences for renewable energies, can modify in a positive manner the implementation of solar heater systems not only under the financial point of view but also under environmental considerations.

The scope of the study is limited to an isolated community in Imbabura, nevertheless this initiative should be extended to all zones in Ecua-

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dor because of its solar potential, mainly in Galápagos where the electricity grid infrastructure is still insufficient and the fact of using fossil fuels in this zone has bigger impacts due to its ecological vulnerability.

The comparison between the future prices of LPG in scenarios 2DS, 4D6, 6DS, and IEA projections suggests that scenario 4DS is the most reliable option to plain the prospective. Because according to IEA, this trend scenario has closer values to the cost of energy in future, so the payback periods would start since 2.48 to 4.67 years.

Under the environmental point of view, this initiative contributes to forgo the release of 558kg of CO2 per year per family to the atmosphere, because each home would give up to burn 192.96 kg of LPG per year. (IPCC, 2006).

7. ACKNOWLEDGMENT

It is worth mentioning the contribution of Dr. Jesús López, partner of INER, for providing the F Chart Model which enables the determination of solar potential. Also the revision of Eng. Diego Vaca for reviewing and suggesting to incorporate solid foundations to select the location and the prospective prices of fuels.

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