TECHNO-ECONOMIC ANALYSIS OF ROOFTOP PHOTOVOLATAIC-THERMAL COLLECTORS' INSTALLATIONS IN RESIDENTIAL ENERGY COMMUNITIES

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ABSTRACT

In response to climate action and to mitigate energy poverty, it is imperative to intensify efforts towards increasing the share of renewable energies and ensuring energy efficiency in this sector. In its commitment to the energy decarbonization, Spain has made a commitment to attain a 42% contribution of renewable energy contribution to its total energy mix by 2030. The residential sector of Spain is responsible for about 17% of the national final annual energy consumption and about 6% of energy-associated CO_2. Residential buildings' rooftops present avenue for harnessing solar energy with the advantages of avoidance of the need for additional land space for solar collector fields and promote self-generated energy consumption. Though hybrid photovoltaic-thermal collectors simultaneously harness both the photovoltaic and thermal potentials of incident solar radiation, there have been limited adoption of these collectors in renewable energy systems. This study explores a framework of incorporating rooftop photovoltaic-thermal collectors in residential communities by limiting the initial installation components and financial cost. This was pursued using the case study of the 184 municipal residential communities of the Tarragona province of Spain. The results obtained indicate that even without incorporating thermal and electrical storages, the solar fraction in the energy consumption for domestic hot water and electricity will be increased in all the municipalities along with economic and environmental benefits.

1 INTRODUCTION

Energy demand in the residential sector has a significant share in the global energy consumption of about 30% and it is associated with about 26% of global emissions (IEA, 2023). In response to climate action and to mitigate energy poverty, it is imperative to intensify efforts towards increasing the share of renewable energies and ensuring energy efficiency in this sector (Diaoglou et al., 2022). In its commitment to the energy decarbonization, Spain has made a commitment to attain a 42% contribution of renewable energy contribution to its total energy mix by 2030 (IEA, 2021). The residential sector of Spain is responsible for about 17% of the national final annual energy consumption and about 6% of energy-associated CO_2 emissions (IEA, 2021). The abundant solar energy potentials across the country presents a brilliant opportunity for the country to meet its renewable energy targets (Yu et al., 2022). Residential buildings' rooftops present avenue for harnessing solar energy with the advantages of avoidance of the need for additional land space for solar collector fields and to promote self-generated energy consumption (Shen et al., 2021).
Spain receives one of the highest solar insolation in the Europe Union, with annual averages of between 1600 hours and 3000 hours of sunshine across the country per year (García-López et al., 2023). It is therefore imperative that the country should leverage on the abundance of this solar energy resource in realizing its energy plans. Despite the advantage of hybrid photovoltaic-thermal (PV-T) collectors to simultaneously harness both the photovoltaic and thermal potentials of incident solar radiation, there have been limited adoption of these collectors in renewable energy systems (Herrando et al., 2023). According to Osman et al. (2023), one impediment to the full adoption of most matured renewable energy technologies is the initial high cost of deployment. From the work presented by Herrando et al. (2018) on the cost competitiveness of a solar combined heating and power system based on an optimized

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flat-box rooftop PV-T collector for use in single residential buildings, the cost of hot water storage tanks and electrical batteries accounted for about 23% of initial investment cost. There is therefore the need to fashion out means of lowering the initial installation cost of the PV-T based systems to encourage the adoption of this technology. This study explores the feasibilities of limiting the initial installation cost of the adoption of the PV-T technology in residential energy communities through the elimination of thermal and electrical storages, pumps, and complex water flow control systems. This is with the hope of highlighting the clean energy potentials of the PV-T technology and thus, encourage its adoption for integration into renewable energy systems in residential communities. The potential benefits of this approach are investigated in this study, through a techno-economic analysis with a preview into the potential environmental benefits that it may offer.

2 METHODOLOGY

2.1 Physical Model

This study proposes the use of flat-box water-based photovoltaic-thermal collectors which are mounted on the rooftops of municipal residential buildings. The flow of water into the PV-T collectors, from the municipal water supply pipes, is to be controlled by photo-sensitive water flow controllers which allow water flow at a constant volume flow rate through the collectors when there is solar irradiation ($G > 0$) and stop the flow when there is no solar irradiation ($G = 0$). This physical model is depicted in the schematic diagram on Figure 1, where the water outlets of individual PV-T collectors are connected in parallel array. The PV-T collectors' outputs are connected to the residential domestic hot water (DHW) boilers for auxiliary heating. The direct current (DC) electricity produced by the photovoltaic modules in the collectors will be converted to alternating current (AC) by electrical inverters and then fed to the municipal electricity supply grid.

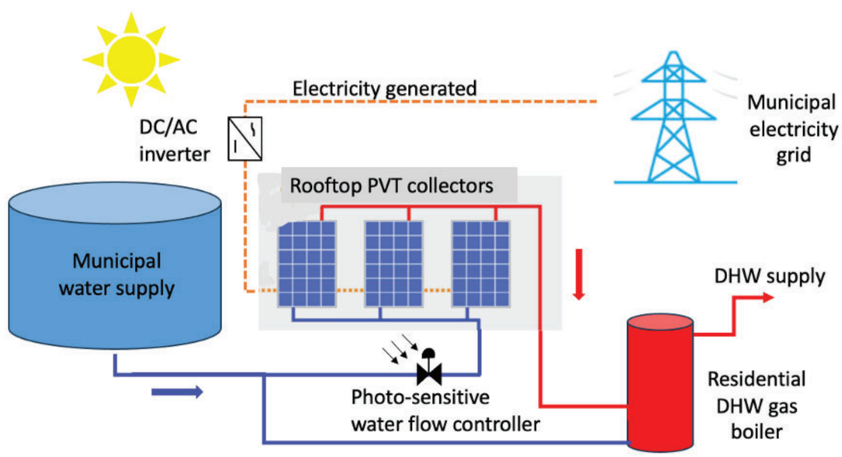

Figure 1: A schematic of the physical model of the proposed configuration.

2.2 Case Study

The case study of the residential communities of the Tarragona province of Spain, which is comprised of 184 administrative municipalities, which are shown in Figure 2, was employed. The province is in the North-eastern part of Spain (geographical coordinates: 0.25-1.63, 40.54-41.56), with Mediterranean climatic conditions.

2.3 Computational approach

Figure 3 shows the algorithm followed for the computations that was involved in this study which was basically driven by publicly published datasets.

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Figure 2: A map of Tarragona province showing the different administrative municipalities.

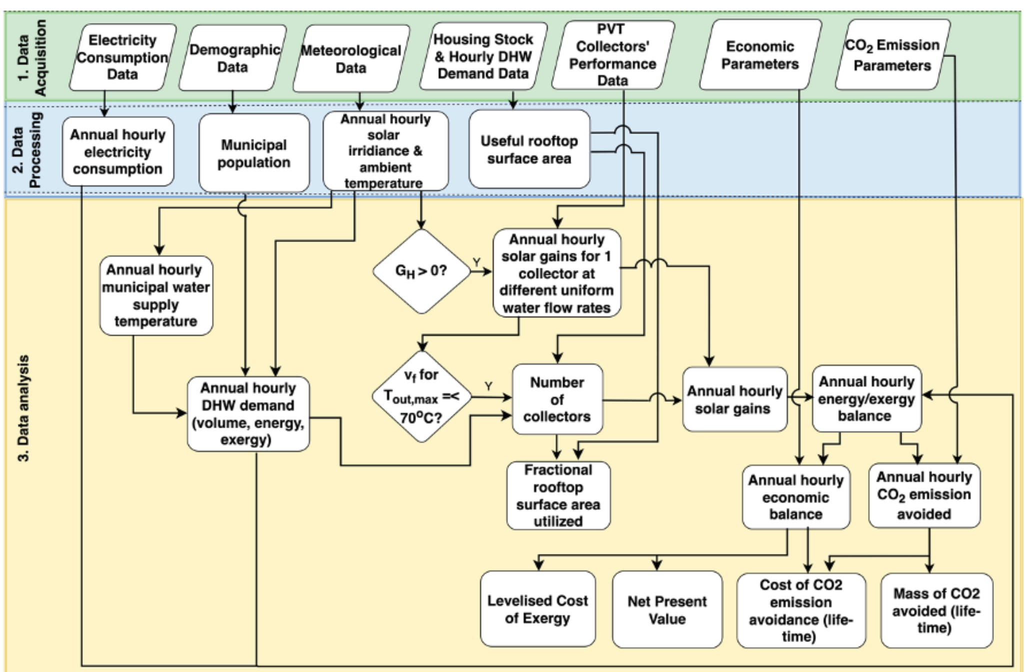

Figure 3: The algorithm of the solution.

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The hourly electricity consumption data for the year 2019 hourly electricity for the residential sector of each municipality was obtained from the online platform of Datadis (n.d.) was taken to represent the typical consumption pattern. The 2023 municipal population data were obtained from the online platform of the Spanish National Institute of Statistics (in Spanish, INE) (n.d.-a).
The typical annual hourly weather parameters utilized for each municipality was obtained from typical meteorological year files downloaded from the online platform of Photovoltaic Geographical Information System (PVGIS) (n.d.).The total useful rooftop space on the residential buildings in each municipality was estimated from the data on residential housing stock characteristics and demographics that were published by the Spanish Ministry of Development (2020) and the Spanish National Institute of Statistics (in Spanish, INE) (n.d.-b). The DHW hourly profile published by the Spanish Ministry of Transport, Mobility and Urban Agenda (2022) was utilized.
This study assumed the use of a flat-box photovoltaic-thermal collector like the type whose heat transfer properties was investigated by Sun et al. (2021). The technical properties of the PV-T collector are given in Table 1.

Table 1. Technical parameters for the flat-bx PV-T collector considered in this study.

Parameter	**Value**
PV cell type	Multi-crystalline Silicon
Glazing type	Tempered glass
Absorber material	Copper
Number of layers of glazing	1
Aperture area per collector, A_c	1.427 m^2
Electrical efficiency of PV module, η_{STC}	16 % (@STC)
PV module's temperature coefficient, γ	0.37 %/ºC
Maximum electrical power per collector	200 W_p
Optical efficiency of glazing, η_o	0.8
PV-T module's thermal efficiency factor, F'	0.8446
PV module's heat loss factor, U_L	6.6382 W/m^2
PV module's annual degradation factor	0.5% per annum
Soiling loses	0.5% Per annum

Table 2. The economic parameters for this study.

Parameter	**Value**
Cost of collector (€/m^2)	250
Cost of inverters & electrical cables (€/m^2)	100
Cost of hydraulic circuit (€/m^2 of collector)	100
Cost of assembling (€/collector)	125
Cost of O&M (based on cost of collectors)	5 %
Harmonized energy price inflation rate, e	7.6 %*
Discount rate, d	5 %
Natural gas price, GP (€/kWh)	0.078
Interest rate, i	0.16 %**

* 5-years (2019-2023) average harmonized energy index of consumer prices inflation rate in Spain (Statista, n.d.-a)
** 10-years (2013-2022) average national interest rate for Spain (Statista, n.d.-b).

The economic parameters employed in this study are listed in Table 2. This study employed the average electricity price (EP) scenario for the Spanish electricity market as presented in Table 4 (Saez et al., 2023):

Table 3. Average electricity prices.

Hour	**0 - 8**	**8 - 10**	**10 - 14**	**14 - 18**	**18 - 22**	**22 - 24**	**Weekends**
Cost (c€/kWh)	12	18	24	18	24	18	12

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Table 4. CO_2 emission parameters.

Parameter	**Value**
Emission associated with grid electricity (gCO_2/kWh_e)	217.37 (Statista, n.d.-c)
Emission from natural gas boilers (gCO_2/kWh_{th})	271.00 (Lin et al., 2021)

A fixed rate of *9 c€/kWh* for selling electricity to the grid was applied. This study assumed that natural gas boilers are normally used in the residential dwellings for the provision of DHW energy and that electricity is usually supplied from the grid. These data were instrumental in computing the equivalent CO_2 emission associated with DHW and electricity uses in the study area. And thus, the equivalent CO_2 emission avoided by the proposed intervention was computed. The data in Table 4 have been used in this study.

2.4. Data Analysis

The daily temperature of water from the municipal supply was computed by employing the model proposed by the National Renewable Energy Laboratory, USA (Hendron et al., 2004; Żukowski, 2020):

$$T_w = 1.8\left(T_{a,avg} - 14.44\right) + 64 + \left[Ratio\left(\frac{T_{a,max} - T_{a,min}}{1.11}\right)\sin(0.9863(Day\ No. - 15 - Lag) - 90)\right] \quad (1)$$

where,
$$Ratio = \left(0.4 + 0.018\left(T_{a,avg} - T_{a,norm}\right)\right) \quad (2)$$

$$Lag = 35 - \left[1.8\left(T_{a,avg} - T_{a,norm}\right)\right] \quad (3)$$

where $T_{a,norm}$ is the nominal ambient temperature which was taken as 10 ℃; $T_{a,avg}$ is the annual average ambient temperature; $T_{a,max}$ is the maximum average monthly ambient temperature; $T_{a,min}$ is the minimum average monthly ambient temperature; and $Day\ No.$ is the day-of-the-year number. The daily temperature of tap water was assumed to be uniform for all the hours of each day. The daily DHW demand was computed based on *0.03* m^3 at 60 ºC per person. Therefore, the quantity of daily DHW energy demand (*Q*) per municipality was computed by:

$$E_{DHW,demand}(J) = 0.03Pop(\rho_w \times c_w \times (60 - T_{in})℃ \quad (4)$$

where, *Pop* is the municipal population, ρ_w is the density of tap water and c_w is the specific heat capacity of tap water. Hourly DHW energy was then calculated by multiplying *Q* by the fraction corresponding to each hour according to the demand profile obtained from Ministerio de Transportes (2022).

The electrical and thermal gains for the PV-T collectors were obtained by employing the methods employed by Sun et al. (2021), where nominal operating cell temperature (NOCT) of the PV module for each hour was determined by:

$$NOCT_{PVT} = \left(800F_R\left(\frac{T_{in} - T_a}{G}\right)\right) + \left(\frac{F_R(\eta_o)}{F_R U_L}(1 - F_R)800\right) + 20 \quad (5)$$

where, F_R, the PV-T module's heat removal factor was determined by:

$$F_R = \frac{\dot{m}c_p}{A_c U_L}\left[1 - exp\left(-\frac{A_c F' U_L}{\dot{m}c_w}\right)\right] \quad (6)$$

The PV module's average temperature at each hour was then estimated using:

$$T_{PV} = [T_a + (NOCT_{PVT} - 20)]\frac{G}{800} \quad (7)$$

where T_a is the ambient temperature and G is the hourly average of the solar irradiance.

The electrical efficiency of the PV module was then computed by:

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$$\eta_{el,PVT} = \eta_{STC}[1 - \gamma(T_{PV} - T_{STC})] \tag{8}$$

where T_{STC} is the temperature at Standard Testing Condition (STC) which was taken as 25 °C. Therefore, the average electrical energy from PV-T module each hour, was determined by:

$$E_{el,PVT}(kWh) = \frac{GA_c\eta_{el,PVT}}{1000} \tag{9}$$

where A_c is the aperture area of PV-T collector.
The average hourly thermal energy gained by water flowing through the PV-T collector per hour was determined by:

$$E_{th,PVT}(kWh) = \frac{A_c[(F_R\eta_o G) - F_R U_L(T_{in} - T_a)]}{1000} \tag{10}$$

while the average hourly temperature of water output from PV-T collector was determined by:

$$T_{out}(°C) = T_{in} + \frac{A_c}{\dot{m}c_w}[F_R\eta_o G - F_R U_L(T_{in} - T_a)] \tag{11}$$

where $\dot{m}$ is the mass flow rate of water through PV-T collector.

2.4.2. Energy and Exergy analysis

Using the typical annual weather data for each municipality, with the calculated hourly municipal water supply temperatures, dynamic computer simulations were run with uniform water flowrates into single PV-T collector. Uniform flowrates of 1 *L/min*, 0.5 *L/min* and 0.25 *L/min* were separately applied to one collector in each municipality, with flow activated for hours with incident solar radiation (i.e. *G>0*). The water flow rate of 0.25 *L/min* gave maximum temperature of water exiting a PV-T collector (T_{out}) throughout a typical year at all the municipalities at 70 ºC (i.e. $T_{out,max} \leq 70$ °C) and it was selected. The number of PV-T collectors for each municipality was then calculated based on DHW demand by:

$$Number\ of\ PV - T = ROUNDUP\left[\frac{Average\ of\ hourly\ DHW\ volume\ demand}{Hourly\ water\ volume\ flow\ through\ each\ collector}\right] \tag{12}$$

The useful hourly solar gains (electrical and thermal) were then computed for each municipality based on the number of PV-T collectors therein.
Exergy analysis of thermal systems provides more precise performance evaluation by considering the thermodynamic loses that may accompany heat transfer. Thus, the hourly DHW thermal energy demands and the hourly useful thermal energy gains from PV-T collectors ($E_{DHW,PVT}$) were converted to their thermal exergy equivalents, relative to the ambient temperatures by:

$$Ex_{DHW,demand}(kWh) = E_{DHW,demand}\left(1 - \frac{T_a(K)}{60+273(K)}\right) \tag{13}$$

$$Ex_{DHW,PVT}(kWh) = E_{th,PVT}\left(1 - \frac{T_a(K)}{T_{out}(K)}\right) \tag{14}$$

where E_{DHW} was first converted to its equivalent in kWh. The hourly electrical energy demand and that generated by the PV-T collectors are equal to the corresponding electrical exergies respectively (i.e. $E_{el,demand} = Ex_{el,demand}$ and, $E_{el,PVT} = Ex_{el,PVT}$).
Energy and exergy balances were then computed for each municipality based on hourly exergy demands (electricity and DHW) and exergy gains from the proposed PV-T collectors' installations through a typical year.

2.4.2. Economic Analysis

To determine the economic viability of the PV-T collectors' installations, the Net Present Value (*NPV*) for each municipality was computed by:

$$\text{Net}\ Present\ Value\ (NPV) = \sum_{y=0}^{24}\frac{R_y(1+e)^y}{(1+i)^y(1+d)^y} - \left(C_{Capital} + \sum_{y=0}^{24}C_{O\&M}\right) \tag{15}$$

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where y is the year starting from the year of installation being 0, $C_{Capital}$ is the initial capital investment of installation, $C_{O\&M}$ is the total cost of operation and maintenance, R_y is the annual financial savings expected from the PV-T collectors' installation in each municipality and was calculated by Aguilar-Jiménez et al, 2020):

$$R_y = \sum\left(EP * E_{el,PVT}\right)_{consumption,y} + \sum\left(ES * E_{el,PVT}\right)_{sold,y} + \sum\left(GP * E_{th,PVT}\right)_{consumption,y} \quad (16)$$

Any excess electricity generated each hour by the PV-T collectors were exported and sold to the grid. Any excess thermal energy/exergy from the PV-T collectors was considered lost.

2.4.3. *CO_2* emission avoidance analysis

The mass of equivalent CO_2 emissions associated with annual electricity and DHW consumption in the residential communities of the different municipalities were calculated by:

$$M_{CO_{2},Demand} = \left(E_{el,demand} * 217.37\ gCO_2\right) + \left(E_{DHW,demand} * 271.00\ gCO_2\right) \quad (17)$$

The mass of equivalent CO_2 emissions avoided by the PV-T installations in each municipality was calculated by:

$$M_{CO_{2},PVT} = \left(217.37\ gCO_2 * \sum_{y=0}^{24} E_{el,PVT}\right) + \left(271.00\ gCO_2 * \sum_{y=0}^{24} E_{th,PVT}\right) \quad (18)$$

The specific cost of CO_2 emission abatement provided by the PV-T collector installations was determined by:

$$Specific\ cost\ of\ CO_2\ emission\ abatement = \frac{C_{Capital} + \sum_{y=0}^{24} C_{O\&M}}{\sum_{y=0}^{24} M_{CO_{2},PVT}} \quad (19)$$

3 RESULTS AND DISCUSSION

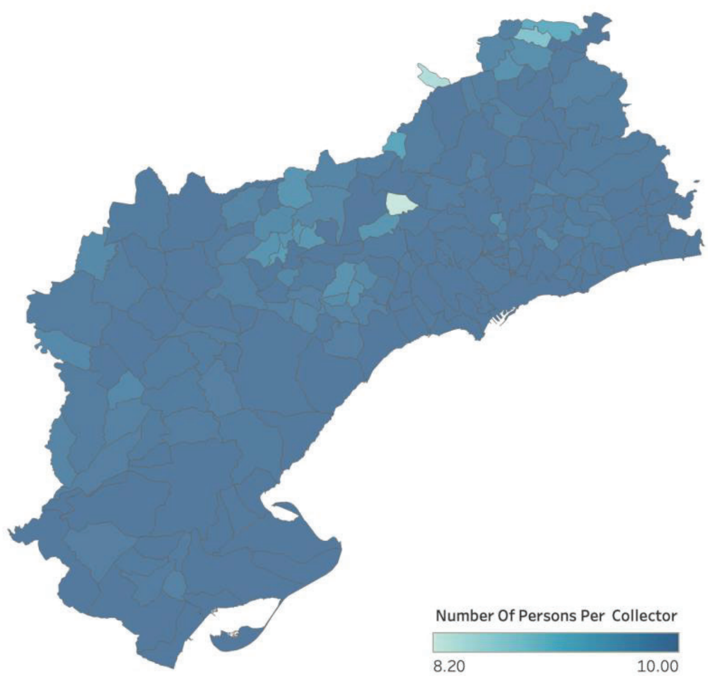

Figure 4: Average number of persons per PV-T collector in each municipality of Tarragona province.

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Figure 4 shows the average number of persons served by one PV-T collector in each municipality, according to the approach followed in this study. The average distribution across the province is 10 persons per collector. The deviations observed in Figure 4 with the municipalities in the lighter shades of color (less than 10 persons per collector) are due to possible over-estimation of the numbers of PV-T collectors which was caused by rounding up values which were significantly less than the next higher whole numbers. The largest deviation can be observed at La Febró where there are about 8.2 persons to one collector. Nevertheless, most municipalities show very close values to the average value of 10 persons per collector, which appears to give the optimal distribution. Thus, there is an indication that a PV-T collector area of about 0.143 m^2 per capital, through the province, may be optimal within the framework of this study. In all, 82,332 PV-T collectors were designed to be installed throughout the province, covering only about 4.4 % of the total useful rooftop surface area available on the residential buildings in the province. This ranged from about 0.77 % in Vallfogona de Ruicorb to about 24.23 % in La Canonja. It is important to note that this percentage is influenced by municipal population (average volume of DHW demand) and the prevalence of either single-family buildings or multi-family buildings (available rooftop surface area per capita) in the municipality. Vallforgona de Ruicorb with an average population density per dwelling of about 0.5, indicates that atleast about half of the number dwellings present in the municipality are uninhabited. While in La Canonja, the average population density per dwelling is 7.2, which explains the larger area of collector coverage per available rooftop surface area.
The annual hourly DHW exergy and the hourly electrical exergy demands across all the 184 municipalities were aggregated, and in similar manner were the annual hourly thermal exergies and electrical exergies aggregated. Of the total DHW exergy demand annual of about 55.27 GWh, the PV-T collectors delivered about 14.71 % (~8.13 GWh) which is represented in Figure 5(a). The minimum percentage DHW exergy delivered was 11.92% in the case of the PV-T installations in Prades while the maximum of 16.41 % was found in Les Borges Del Camp. Alongside, the PV-T collectors collectively delivered about 2.07 % (~37.13 GWh) of the annual electrical exergy demand (~1.40 TWh) as presented in Figure 5(b). The minimum percentage electricity generated by the PV-T collector installations was in La Palma D'Ebre where about 0.13% of annual demand was satisfied while the maximum of about 8.73% was in Santa Coloma de Queralt. Overall, the PV-T collector installations afforded an average solar fraction of about 2.55% in the DHW and electricity consumption in the province. This ranged from La Palma D'Ebre with a total solar fraction of about 0.17 % and Santa Coloma de Queralt with 9.33%. A minimal total excess of about 6 % of the aggregated hourly thermal exergy was generated by the PV-T collectors and this was not computed with the results presented.
The aggregated cost of PV-T collectors, accessories and installation across the province was about €63.16 million (~€3875.75 in La Febró – €10.45 million in Tarragona) with associated total annual O&M cost of about € 1.47 million (€89.19 – €242,857.56). The NPV per PV-T collector for a 25-year installation was calculated for each municipality and this is presented in Figure 6. It is obvious that the PV-T installations with the mode of operations considered in this study are financially feasible in all the municipalities with the NPV per collector ranging from € 2773.70 in Senan, to € 3280.00 in Les

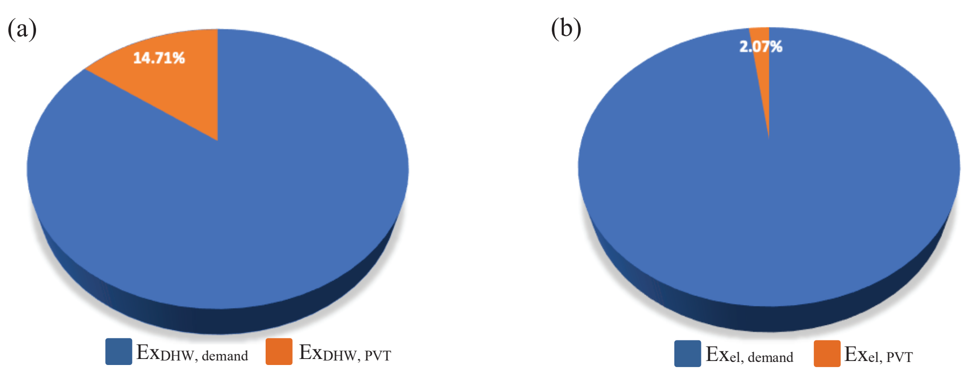

Figure 5: Percentage of the annual (a) domestic hot water exergy demand (b) electrical exergy demand, supplied by the PV-T collectors in the province.

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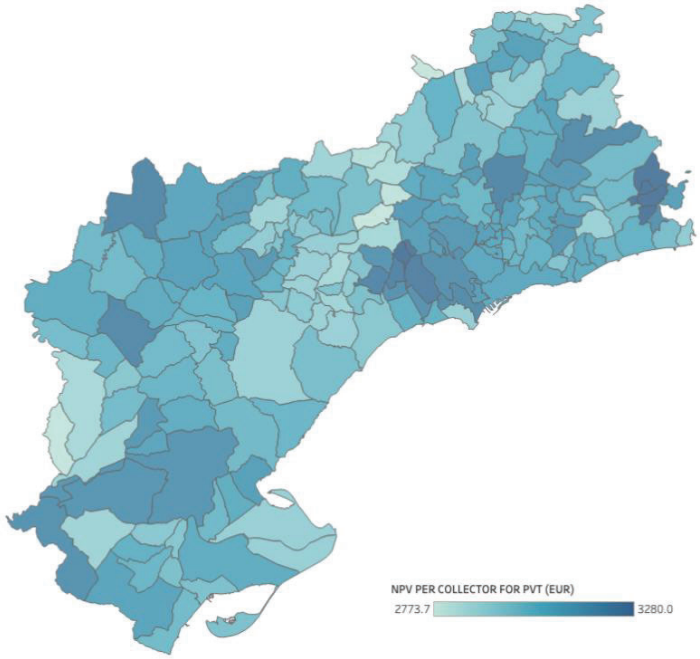

Figure 6: NPV per PV-T collector installed in each municipality of Tarragona province.

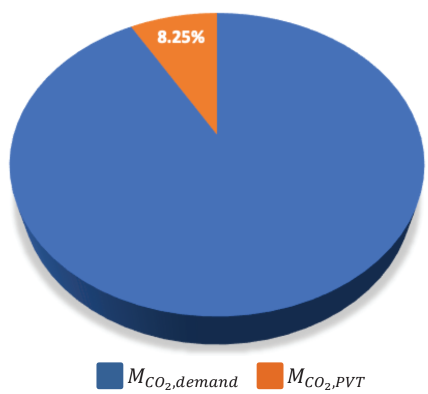

Figure 7: Annual percentage of equivalent CO_2 emissions associated with electricity and DHW consumption avoided by the PV-T collector installations in Tarragona province.

Borges del Camp. The total NPV for all the PV-T collector installations through the province is about € 252.39 million which indicates that the framework presented in this study is both viable and profitable. Though this is characterized by long average payback time with average of about 7.6 years (~7.2 – 8.1 years) through the province.

The annual mass of equivalent CO_2 emissions avoided by the PV-T collector installations was aggregated across the province for both the electricity generated and for the DHW exergy supplied. Figure 7 shows the aggregated percentage of equivalent CO_2 emission associated with electricity and DHW consumption that would be avoided in Tarragona province annually through the adoption of the PV-T collector installations in each municipality. The PV-T collector installations would afford an annual avoidance of about 8.25 % (~34.56 kt CO_2-eq) of the annual equivalent CO_2 emissions associated with electricity and DHW consumption (~418.72.56 kt CO_2-eq) throughout the province. The specific cost of equivalent CO_2 emission abatement afforded by the PV-T installations, over a 25-year lifetime, was estimated per municipality and presented in Figure 8. The lowest value of about €

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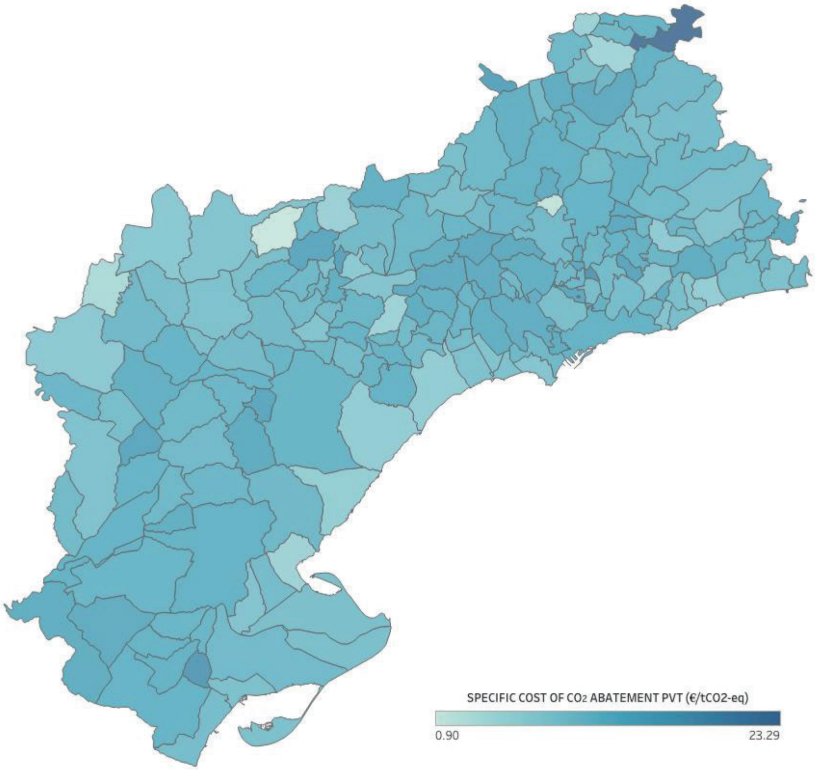

Figure 8: Specific cost of CO_2 abatement afforded by the PV-T collector installations across the municipalities of Tarragona.

0.90/tCO_2-eq is afforded by the PV-T installations in La Palma D'Ebre while the maximum is found with the installations in Santa Coloma de Quelralt at €23.29/tCO_2-eq. The average specific cost of equivalent CO_2 emission abatement provided by all the PV-T collectors across the province, over their lifetime, is about € 10.77/tCO_2-eq.

4 CONCLUSIONS

This study proposes a strategy for a piecewise approach for the gradual integration of rooftop water-based photovoltaic-thermal (PV-T) based systems in residential energy communities to limit the initial cost of installation of a complete system. This framework explored the option of limiting the initial installation cost of PV-T based energy system by eliminating thermal and electrical battery storages, mechanical pumps, and complex water flow control systems. The case study of the 184 municipalities of Tarragona province of Spain have been utilized, using real weather, electricity consumption, buildings' rooftop surface availability, and demographic data as inputs while simulations were done based on hourly resolution. The insight from the study revealed that about 4.4 % of the useful residential buildings' rooftop surface area in the province, an average of about 0.143 m^2/capita, is required for the PV-T collectors' installation through this energy community approach. This is with uniform water flow rate from municipal water supplies at 0.25 l/min during respective daylight hours. This would translate to an average solar fraction of about 14.71 % (~69.22 kWh/m^2/year) for domestic hot water exergy consumption and about 2.07% (~246.77 kWh/m^2/year) for electricity consumption can be injected into the annual energy supply mix in the province. This would also enable an annual avoidance of about 8.25 % (294.17 kgCO_2-eq/m^2/year) of the annual CO_2 emissions associated with domestic hot water and electricity consumption in the province. The PV-T installations show economic viability in all the municipalities with an average NPV of about € 3065.54/m^2 of PV-T collector installation if left operating for 25 years. With the minimal average initial investment of about € 76.79/capita and about

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€ 1.79/capita on the average for O&M, coupled with the financial savings offered by these installations, affordability of energy would be enhanced for the residents of Tarragona province. Though this would be associated with long average payback time of about 7.6 years if the installations are not integrated with other components through their lifetimes. Upon this premise, these PV-T installations would offer an average low specific cost of CO_2 emission abatement with an average of about € 10.77/tCO_2-eq through the province. However, to optimize the potentials offered by rooftop PV-T installations, the system may be expanded later (within the lifetime) subject to the availability of additional funds. This may involve the integration of more collectors, supplementary hot water storage tanks and variable water flow controls. The installations may also be expanded to cover space heating demands, by coupling it with heat pumps. The positive outcomes highlighted by this study demands greater consideration of the integration of water-based rooftop PV-T collectors into the renewable energy framework of the residential sector of the Tarragona province of Spain.
The framework presented in this study may be applied at any other location where there the necessary data are available, to provide insight about the potential gains from rooftop PV-T collector installations.

NOMENCLATURE

A	collector area (m^2)
C	cost (€)
d	discount rate (%)
Day No.	day-of the-year number (1, 2,..,365)
e	price escalation rate (%)
E	energy (J or kWh)
EP	electricity purchase price (€/kWh)
ES	electricity selling price (€/kWh)
Ex	exergy (J or kWh)
F'	thermal efficiency factor (-)
F_R	heat removal factor (-)
G	average solar irradiation (W/m^2)
GP	natural gas price (€/kWh)
i	national interest rate (%)
$\dot{m}$	mass flow rate average (kg/s)
M	mass of equivalent CO_2 ($kgCO_2$-eq)
NOCT	nominal operating cell temperature (^oC)
PV-T	photovoltaic-thermal (-)
G	average solar irradiation (W/m^2)
T	temperature (^oC or K)
U_L	heat loss factor (W/m^2K)
η	efficiency factor (-)
γ	temperature coefficient (%/^{o}C)

Subscript

a	ambient
avg	annual average
capital	initial capital investment
in	inlet
norm	nominal
out	outlet
O&M	operation and maintenance
p	participants
th	thermal
w	water
y	year number

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