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Hybrid PV and solar-thermal systems for domestic heat and power provision in the UK: Techno-economic considerations

María Herrando [a,b], Christos N. Markides [a,*]

[a] Clean Energy Processes (CEP) Laboratory, Department of Chemical Engineering, Imperial College London, London SW7 2AZ, United Kingdom
[b] Centre of Research for Energy Resources and Consumption (CIRCE), University of Zaragoza, Mariano Esquillor 15, 50018 Zaragoza, Spain

HIGHLIGHTS

- Renewable heat and power generation in UK homes with PVT systems studied.
- PVT/w generation: 2.3 MW_e h/yr (51% of demand) and 1.0 MW_{th} h/yr (36% hot water).
- Optimised PVT/w system has 9–11 year payback periods (PV-only: 6.8 years).
- Same system allows 16.0-t CO_2 reduction and 14-t primary fossil-fuel saving.
- With a ∼2:1 support (£/W_e h:£/W_{th} h), PVT and PV have similar payback periods.

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ABSTRACT

A techno-economic analysis is undertaken to assess hybrid PV/solar-thermal (PVT) systems for distributed electricity and hot-water provision in a typical house in London, UK. In earlier work (Herrando et al., 2014), a system model based on a PVT collector with water as the cooling medium (PVT/w) was used to estimate average year-long system performance. The results showed that for low solar irradiance levels and low ambient temperatures, such as those associated with the UK climate, a higher coverage of total household energy demands and higher CO_2 emission savings can be achieved by the complete coverage of the solar collector with PV and a relatively low collector cooling flow-rate. Such a PVT/w system demonstrated an annual electricity generation of 2.3 MW h, or a 51% coverage of the household's electrical demand (compared to an equivalent PV-only value of 49%), plus a significant annual water heating potential of to 1.0 MW h, or a 36% coverage of the hot-water demand. In addition, this system allowed for a reduction in CO_2 emissions amounting to 16.0 tonnes over a life-time of 20 years due to the reduction in electrical power drawn from the grid and gas taken from the mains for water heating, and a 14-tonne corresponding displacement of primary fossil-fuel consumption. Both the emissions and fossil-fuel consumption reductions are significantly larger (by 36% and 18%, respectively) than those achieved by an equivalent PV-only system with the same peak rating/installed capacity. The present paper proceeds further, by considering the economic aspects of PVT technology, based on which invaluable policy-related conclusions can be drawn concerning the incentives that would need to be in place to accelerate the widespread uptake of such systems. It is found that, with an electricity-only Feed-In Tariff (FIT) support rate at 43.3 p/kW h over 20 years, the system cost estimates of optimised PVT/w systems have an 11.2-year discounted payback period (PV-only: 6.8 years). The role and impact of heat-based incentives is also studied. The implementation of a domestic Renewable Heat Incentive (RHI) at a rate of 8.5 p/kW h in quarterly payments leads to a payback reduction of about 1 year. If this incentive is given as a one-off voucher at the beginning of the system's lifetime, the payback is reduced by about 2 years. With a RHI rate of 20 p/kW h (about half of the FIT rate) PVT technology would have approximately the same payback as PV. It is concluded that, if primary energy (currently dominated by fossil fuels) and CO_2 emission minimisation are important goals of national energy policy, PVT systems offer a significantly improved proposition over equivalent PV-only systems, but at an elevated cost. This is in need of careful reflection when developing relevant policy and considering technology incentivation. Currently, although heat outweighs electricity consumption by a factor of about 4 (by energy unit) in the UK domestic sector, the support landscape has strongly favoured electrical microgeneration, being inclined in favour of PV technology, which has been experiencing a well-documented exponential growth over recent decades.

* Corresponding author at: Clean Energy Processes (CEP) Laboratory, Department of Chemical Engineering, Imperial College London, South Kensington Campus, London SW7 2AZ, United Kingdom. Tel.: +44 20 759 41601.

E-mail address: c.markides@imperial.ac.uk (C.N. Markides).

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Nomenclature

Abbreviations

BOS	Balance of System costs
COP	Coefficient of Performance
CPBT	Cost Payback Time
CPI	Consumer Price Index
DPB	Discounted Payback Period
FIT	Feed-In Tariff
MPP	Maximum Power Output
NPV	Net Present Value
NOCT	Normal Operation Cell Temperature
LPC	Levelised Production Cost
LCC	Levelised Coverage Cost
LCS	Life Cycle Savings
PV	photovoltaic
PVT	photovoltaic and solar-thermal system
PVT/w	photovoltaic and solar-thermal water system
RHI	Renewable Heat Incentive
RHPP	Renewable Heat Premium Payment
a-RHPP	Augmented Renewable Heat Premium Payment
a-RHPP*	Optimum Augmented Renewable Heat Premium Payment
RPI	Retail Price Index
STC	Standard Test Conditions

Symbols

β_0	temperature coefficient for the PV module (1/K)
A_i	annual costs incurred by the system (£/year)
A_{inet}	annual costs incurred by the system (£/year) once the RHI is discounted ($A_{inet} = A_i$ – RHI)
C_0	total upfront cost of a project (£)
C_{aux}	total running costs of the auxiliary heater throughout the year (£/year)
C_{cE}	total running costs of buying the overall electricity demand from the grid throughout the year (£/year)
C_{cHW}	total running costs of a conventional system throughout the year (£/year)
C_e	electricity price (p/kW$_e$ h)
C_{NG}	natural gas price (p/kW$_{th}$ h)
$C_{O\&M}$	operation and maintenance costs of the unit throughout the year (£/year)
C_{PVE}	total running costs incurred to cover the demand when a PV-only unit is installed (£/year)
C_{PVTE}	total running costs incurred to cover the demand when a PVT unit is installed (£/year)
C_{sE}	percentage of cost savings due to the electricity demand covered by the PVT system (%)
C_{sHW}	percentage of cost savings due to hot-water production (%)
d	discount rate for the PVT system (%)
d_c	discount rate for the conventional system (%)
DC$_{av}$	percentage of the average overall demand covered by the PVT system (%)
DC$_E$	percentage of the electricity demand covered by the PVT system (%)
DC$_{HW}$	percentage of the hot-water demand covered by the PVT system (%)
DC$_{wav}$	percentage of the weighted average overall demand covered by the PVT system (%)
DPB	Discounted Payback Period (years)
E_{grid}	electrical energy required from the grid over a full year (kW$_e$ h)
E_{loss}	electrical energy consumed by the water pump (kW$_e$ h)
E_{PVT}	electrical energy produced by the PVT system over a full year (kW$_e$ h)
E_{PVTnet}	net electrical energy generated and available from the household after subtraction of the household's consumption over a full year (kW$_e$ h)
E_T	total annual electricity demand (kW$_e$ h)
E_{wd}, E_{we}	electricity consumption over a day, either during the week or on the weekend respectively (kW$_e$ h)
i	inflation rate (%)
J	incident global solar irradiance on the tilted PVT collector surface (W/m^2)
k	time steps
L	levelised cost (£/year)
LCC$_{av}$	Levelised Coverage Cost per percentage of average demand covered (L (£/year)/DC$_{av}$ (%/year))
LCC$_E$	Levelised Coverage Cost per percentage of electrical demand covered (L (£/year)/DC$_E$ (%/year))
LCC$_{HW}$	Levelised Coverage Cost per percentage of hot-water demand covered (L (£/year)/DC$_{HW}$ (%/year))
LCC$_{wav}$	Levelised Coverage Cost per percentage of weighted average demand covered (L (£/year)/DC$_{wav}$ (%/year))
LPC	Levelised Production Cost (p/kW h)
n, N	lifetime of the PVT system
NPV	Net Present Value (thousand £, or £'000)
P	PV area covering factor (%)
P_{PV}	electrical power output of the PV module (W)
PW$_{LCS}$	present worth of LCS (£)
PW$_n$	present worth of an investment cost at the end of year n (£)
Q_{aux}	total auxiliary energy required over a full year (kW$_{th}$ h)
Q_{gas}	additional amount of heat required (kW$_{th}$ h)
Q_{PVT}	amount of hot-water produced by the PVT system over a full year (kW$_{th}$ h)
Q_T	total household hot-water demand over a full year (kW$_{th}$ h)
RHI	Renewable Heat Incentive (p/kW$_{th}$ h)
T_{cin}	temperature of the water entering the collector (K)
T_{cout}	temperature of the water exiting the collector (K)
T_{del}	delivery temperature of hot water to the household (K)
T_l	delivery temperature of hot water from the auxiliary heater (K)
T_{PVout}	temperature of the water entering the uncovered section without PV (K)
T_{sup}	mains water supply temperature (K)
T_t	temperature of the water in the hot-water tank (K)
T_{tin}	temperature of the collector flow at the inlet of the heat exchanger immersed in the hot-water tank (K)
T_{tout}	temperature of the collector flow at the outlet of the heat exchanger immersed in the hot-water tank (K)
T_{win}	temperature of the water entering the hot-water tank (K)
$(UA)_t$	overall heat transfer coefficient-area product of the heat exchanger located inside the water storage tank (W/K)
V_P	water flow-rate through the collector (with 1 L/h = 2.78×10^{-7} m^3/s)