Photovoltaic-Thermal (PV/T) Hybrid Systems
State-of-the-art technology, challenges and opportunities

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Content

• PV/T in the energy context
• PV/T technology: state-of-the-art
• Typical PV/T applications
• Performance PV/T vs PV + T systems
• PV/T uptake: challenges and opportunities
• Future research on PV/T
• Conclusions
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Source: IRENA 2018 ‘Global energy transformation: A roadmap to 2050’
Energy final use in buildings

EUROSTAT: Final energy consumption in the residential sector by type of end-uses for the main energy products, EU-28, 2016
The potential of solar thermal by 2050

Source: IRENA, Global Energy Transformation 2018

EU target of 1 m2 of solar-thermal installations per person
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PV/T: working principle
Water-based PV/T systems

Flat-plate water collector

Source: Abdelrazik et.al, 2017

Water collector with a jet collision system

Source: H.A. Hasan et.al, 2018
Refrigerant-based PV/T systems

Refrigerant-based PV/T system

Source: Abdelrazik et al., 2017
Air-based PV/T systems

Two-passes heat exchanger with fins

Honeycomb heat exchanger  V-groove heat exchanger

Source: Abdelrazik et.al, 2017
Air-based PV(T) system for space heating

Building Integrated PV/T system (BIPVT) for space heating

Source: Agrawal et. al, 2010
Phase Change Materials (PCM) PV/T

PCM can store large amounts of energy at a constant temperature:

Different topologies of PV-PCM panels:

Source: Joshi et. al, 2018

Source: Maria C. Browne et. al, 2015
Concentrated (C) PV/T

CPVT with parabolic trough and bifacial PV

Source: Solarus product datasheet

CPVT with compound parabolic concentrators and triangular channel receiver

Source: Joshi et. al, 2018
Types of glazing systems on PV/T

Single-layer glazing

multi-layer glazing

Source: Abdelrazik et.al, 2017
Glazing systems

YES because

• Allows a cooling channel above the PV cells
• Allows a spectral filtering before solar radiation hits the PV cells
• Enhances the thermal performance
• Protects the PV cells from environmental influences

NO because

• Of optical absorption in the glazing glass layers
• Results in more expensive panels due to the glazing materials
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Water-based PV/T for domestic use

Target water temperature range: 40 to 65 °C
Water-based PV/T for district/industrial heating

Target water temperature range: 40 to 115 °C

Source: Pakere et al. 2018
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PV + T(hermal)

Evaluation vs PV/T
Theoretical evaluation of performance: PV+T vs PV/T

From the values of datasheets

With
\[ P = \frac{\text{Total power output of the collector}}{\text{Collector gross area}} \]
\[ C = \frac{\text{Collector price}}{\text{Total power output of the collector}} \]

@ STC conditions
\( G = 1000 \text{ W/m}^2 \)
\( T \text{ cells} = 25 ^\circ \text{C} \)
AM1.5 spectrum

\[ P_{PV} = 190 \text{ Wp/m}^2 \]
\[ C_{PV} = 1.22 \text{ €/Wp} \]

\[ P_T = 856 \text{ W/m}^2 \]
\[ C_T = 0.47 \text{ €/W} \]

\[ P_{PV/T} = P_{\text{therm}} + P_{\text{elec}} = 591 \text{ W/m}^2 \]
\[ C_{PV/T} = 0.93 \text{ €/W} \]
PV/T: installed power and installation costs

\[
\begin{align*}
P_{PV} &= 190 \text{ Wp/m}^2 \\
C_{PV} &= 1.22 \text{ €/Wp} \\

P_{PV/T} &= 591 \text{ Wp/m}^2 \\
C_{PV/T} &= 0.93 \text{ €/W} \\

P_T &= 856 \text{ W/m}^2 \\
C_T &= 0.47 \text{ €/W}
\end{align*}
\]

PV and T collectors cannot be stacked on the same surface

- Roof surface optimization
- Simultaneous electrical and thermal power production
Can PV/T power production be higher than power production of a PV+T combination?

S = 100 m²

Highest harvested power

PV

T

PV/T
Can PV/T power production be higher than power production of a PV+T combination?

\[ P_{PV+T;tot} = X \times S \times P_{PV} + (1-X) \times S \times P_T \]

Yes, if \( X > 40 \% \)

\( P_{PV} = 190 \text{ Wp/m}^2 \)
\( P_T = 856 \text{ W/m}^2 \)

\( P_{PV/T;tot} = 591 \text{ Wp/m}^2 \)
Power yield: PV+T vs PV/T

Power performance of PV+T vs. PV/T

Available power per surface unit (W/m²) vs X (% PV)

- Peak power per surface unit Wp/m² PV next to T
- Peak power per surface unit Wp/m² PV/T

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Costs PV/T lower than PV+T?

\[ X \% \text{ PV} + (100-X) \% \text{ T} \]

\[ C_{\text{PV+T tot}} \]

\[ C_{\text{PV}} = 1.22 \text{ €/Wp} \]
\[ C_{\text{T}} = 0.47 \text{ €/W} \]

\[ C_{\text{PV/T tot}} < \]

\[ C_{\text{PV/T}} = 0.93 \text{ €/W} \]

YES, if X > 60 %
Costs PV/T lower than PV+T?

Collector costs PV+T vs. PV/T

Price per produced power unit (EUR/W)

X (%) - PV

Power cost
€/W PV next to T

Power cost
€/W PV/T

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PV/T uptake: challenges

Lower PV/T collector price (€/kW)  
Increase thermal efficiency of PV/T  
Make PV/T more popular

Are these actually opportunities not challenges?
Challenge 1: how to make PV/T cheaper (affordable)?

More companies on the market?
Challenge 2: how to increase thermal (and overall) efficiency of PV/T?

\[ \frac{P_{\text{ther}}}{P_{\text{elec}}} \text{ ratio if } X=65\% \text{ PV} \]

- 65 m² PV
- 35 m² T

\[ P_{\text{elec}} = 12.3 \text{ kW} \]
\[ P_{\text{ther}} = 30.0 \text{ kW} \]
\[ \frac{P_{\text{ther}}}{P_{\text{elec}}} = 2.43 \]

- 100 m² PV/T

\[ P_{\text{elec}} = 19 \text{ kW} \]
\[ P_{\text{ther}} = 85.6 \text{ kW} \]
\[ \frac{P_{\text{ther}}}{P_{\text{elec}}} = 4.5 \].

This ratio is not adaptable, and may not suit the power needs.
Challenge 3: how to make PV/T more popular?

- Demonstration projects (SOLARISE, …)
- Instruct (hands-on trainings) the local installers
- Show PV/T state-of-the-art and state-of-the-practice solutions to general public, students, etc.
Other challenges for the PV/T uptake

How to enhance the reliability of PV/T-systems?

• Early detection of possible PV/T failures
• Increasing PV/T-panels lifetime by better materials/design

<table>
<thead>
<tr>
<th></th>
<th>25-year performance warranty</th>
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<tbody>
<tr>
<td>PV panels</td>
<td></td>
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<tr>
<td>T panels</td>
<td>10-year product warranty</td>
</tr>
<tr>
<td>PV/T panels</td>
<td>25-year PV performance warranty 10-year product warranty</td>
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</table>

Best warranty durations on the market

Limit
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Definition of the yield of PV/T panels

1000 W/m²

Electrical Power Output

Elec. Eff. = \frac{\text{Electrical Power}}{\text{Solar radiation Power}}

20 %

Thermal Power Output

Therm. Eff. = \frac{\text{Thermal Power}}{\text{Solar radiation Power}}

80 %

IEC 61215

EN 12975

100 %
Energy flow in a water-based PV/T panel

Heat losses

1000 W/m²

Electrical Power Output

Transmitted thermal power

Thermal Power Output

Heat losses
Future research on PV/T: yield

Research questions related to the yield of PV/T panels:

• How to define the overall efficiency of a PV/T panel?

• A standard unified norm for PV/T performance assessment is needed: currently the PV and T parts are tested separately in accordance to two norms (PV and T-collectors)
Future research on PV/T: metrology enhanced modeling

Measure and model state-of-the-art PV/T technology:

- Beam-splitting PV/T
- Evacuated tubes PV/T
- Use of Fully-Graded Materials heat absorbers
Beam-splitting PV/T (BSPVT)

Solar radiation

Liquid spectrum filter (static)

Filtered radiation

Solar cells

Wavelength (nm)

10 380 700 3000 10^6

UV VIS NIR IR

HEAT

Possible liquids: silicon oil, therminol, nanofluids, …
Beam-splitting PV/T (BSPVT)

Liquid spectrum filter

- Coconut oil
- Silicon oil
- Water

Solar cells frequency response range

Absorbance

Wavelength (nm)

UV | VIS | NIR

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Evacuated tubes PV/T collectors

PV cells

Water circuit under the PV cells

Vacuum

Hot water outlet

Cold water inlet

Electrical Power
Fully-Graded Materials (FGM) for absorbers

➢ Higher thermal conductivity
➢ Light-weight

➢ But longer production process
Conclusion:

Why PV/T?

Strengths

• Simultaneous, direct thermal and electrical power
• Better PV performance due to fluid cooling
• Suitable for users with increased thermal needs

Opportunities

• New state-of-the-art technologies
• EU 1 m2 solar thermal per capita to be reached
• Consumers are more interested to directly use thermal energy (easy to store as warm water)
Thank you for your attention

Questions?

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For more information

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