SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Technology Position Paper

PVT Collectors and Systems

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A PVT field of collectors on a flat roof is not different from a T field or a PV array. Integrated solutions will look totally similar to PV-only solutions. Credit: Endef - Spain

This document was prepared by Task 60 experts under the direction of JC Hadorn, Solar energies & strategies, Switzerland and Operating Agent of *SHC Task 60: PVT Systems* of the Solar Heating and Cooling Technology Collaboration Programme with input from: Korbinian Kramer, Germany, Maria Herrando, Spain, Laetitia Brottier, France, Glen Ryan, Australia, Daniel Zenhäusern, Switzerland, Ioannis Sifnaios, Denmark, Marco Pellegrini, Italy, JC Hadorn, Operating Agent.

This position paper explains the relevance, potential and current status of the development and market of *hybrid PVT collectors and system concepts*, leading to actions needed to best exploit this technology that combines solar photovoltaic collection and thermal energy production. It addresses policy and decision-makers as well as influencers and aims to present high-level information as a basis for uptake and further development.

1 Introduction and Relevance

The quest to decarbonize society's electrical and thermal systems has never been more urgent. While this decarbonization of the electrical system is on track, the decarbonization of thermal systems is not, and its added complexity has contributed to this. There is also the need for better sector coupling to ensure a resilient energy system to meet these needs. Thermal systems typically make up about 50% of the final energy demand and a large portion of the demand could be serviced by renewable PVT (PV/Thermal) solutions. PVT solutions address another important and increasingly emerging issue – spatial and network constraints. PVT systems deliver high yielding solutions per unit of area and maximize the existing electrical infrastructure through their distributed application.

The purpose of this paper is to highlight PVT's potential, its benefits, and the current barriers to broad market adoption.

In this document, we discuss how to support the development of PVT collectors and systems. PVT technology is a hybrid technology combining a PV (photovoltaic) module and a solar thermal collector (ST); therefore, it produces electricity and heat simultaneously from solar without requiring more space than a PV-only collector would. Cooling (radiative and convective) can also be provided directly during the night using the PVT collector's thermal absorber or indirectly through a machine driven by the PV electricity.

The technology is somewhat more complex than just a PV or a ST collector but provides significant advantages:

1. PVT uses the same area as a PV or ST module to provide electricity and heat, and in some cases cooling.
2. The solar electricity production of an uncovered PVT module is not less than that of a PV-only module. It can be even slightly higher if the collector is operated at temperatures below those of a PV-only module thanks to the thermal energy extracted and used.
3. PVT collectors can be uncovered, glazed or concentrating (with low concentration factors). Depending on their type, PVT collectors can therefore produce heat at temperatures from about -20° to +150°C and serve a wide range of applications throughout the world.
4. The solar thermal production can be used to preheat or heat domestic hot water. In well-designed hybrid collectors, the production can be almost as high

as that of just a ST collector, only 10 to 20% less, a reduction mainly due to the part of the irradiation that is converted to electricity.

5. The thermal energy of the PVT collectors, converted from either solar radiation or ambient heat, can be used as a heat source for a heat pump.
6. The PV part can directly supply the electricity needed for circulation pumps and partially for heat pumps. In some cases, for example a DHW heat pump in summer periods, PV can completely power the heat pump thus leading to a 100% solar solution.
7. Solar generated thermal energy can be stored in many ways, including onsite tanks, precinct level tanks, aquifers, ground strata and pit storage systems. The current storage options are much more cost effective than electricity storage. This is especially true when PVT is used in combination with a heat pump to make good use of the stored energy. The heat pump enables higher output temperatures enabling more compact storage solutions to be implemented. This is important when space is a premium. The larger thermal energy solutions can be accessed via district heating networks and enable the excess heat produced in summer to be stored seasonally for the winter.
8. As the demand for cooling increases, PVT has the potential to address this demand in a number of ways. The first is through direct solutions using the heat in absorption machines. The second is at nighttime when the unglazed PVT collector under clear skies is exposed to the night radiation phenomena. This effect sub cools the working fluid below ambient temperatures and can be used directly and stored. A compact storage example is ice storage. When coupled as a heat pump source, it can be recharged by an unglazed PVT collector with very high efficiencies even during the cold heating season.
9. PVT collectors have a low social impact; they produce no noticeable noise and have no detrimental visual impact when incorporated into a roof or façade.
10. The lifetime of a well-designed PVT collector is expected to be between 20 and 40 years. Case studies of recently developed PVT collectors, however, are still lacking.

The trade-off between the higher cost of a PVT collector and that of separate PV or T collectors must be balanced by the value of the heat or electricity produced on the same occupied area for the system owner. The heat produced can be delivered to a heating network, used onsite or stored in heat storage devices. The electricity produced can be delivered to a grid, used onsite or stored as either electricity or converted to heat. If the electricity is self-consumed, the savings can deeply enhance the Return on Investment (ROI) depending on the local electricity price. This is especially true when substituting alternative heat sources for the combination of heat pump technology; the trade-off costs vs. savings have to be taken into account since boreholes or air heat exchangers are replaced.

PVT systems are used in many applications: single-family and multi-family houses, hotels, campuses, public services, hospitals, agricultural and industrial processes, and even district heating. Payback times as low as 4 years have been observed in hotel case studies in Spanish conditions.

Optimizing a PVT system design and operating philosophy varies significantly depending on the application, size of the system, the spatial constraints and the customer's utility prices. In some cases, this can be quite a complex modeling process to ensure the design meets the customer's operational and financial goals.

2 Current Status

Existing PVT products (collectors) in 2020 can be summarized as follows:

- Uncovered PVT (or WISC) collectors
    - Products: About 80% of the market are liquid- and air-cooled collectors.
    - Market: DHW and space heating in renovated buildings (in combination with a heat pump) and in new buildings (with or without heat pumps, for heating and cooling), space heating for low energy houses using air in the ventilation system or using water in a floor heating solution.
    - Labs: Collectors tested and certified according to PV and/or T standard testing, but still missing a simple global PVT standard at a reasonable price and a simple solution when only the PV module is changed.

- Covered PVT collectors
    - Products: Several are on the market and more are coming.
    - Market: DHW in large buildings – commercial, residential and administrative. Hotels and resorts are an important target.
    - Labs: a global PVT standard is still missing.

- Concentrating PVT collectors
    - Products: A few on the market with a trend to disrupt since the cost of heat tends to be high.
    - Market: DHW and industrial thermal processes.
    - Labs: no global PVT standard is available.

Product market situation:

- Estimated 2 million m^2 installed over the past 5 years (this represents, according to conventional conversion factors, about 270 MW PV and 1,400 MW Thermal).
- Market is slowly growing with very strong competition from PV. In many cases where a heat demand in sunny months is present, PVT is more attractive than PV because it does the same plus heat!
- Increasing number of PVT manufacturers producing high quality products.
- Niche markets: Air PVT in France is a niche market that has boomed over the last years. DHW for hotels with unglazed or glazed collectors is an attractive market segment. The combination of heat pumps with unglazed collectors is a very efficient PVT application that early adopters have caught on to.

- Need to increase installers' awareness of PVT. Trend to franchise installers can be observed.

Research questions that are answered by the PVT community can be described as follows:

- TRL 8 (technology readiness level according to the NASA scale from level 1: a concept to level 9: deployed in a market) is reached for most PVT commercial solutions (new collectors, however, can still be developed).
- How to build durable PVT collectors is known (Task 60 has issued report B2 on the topic).
- PVT collectors with concentration factors of 2 to 5 are developed (but there is less field experience than for non-concentrating PVT collectors).
- PVT built on evacuated tubes have a high TRL by one manufacturer.
- How a PVT collector operates is well known by the manufacturers and reported.
- Which test procedure to apply is known for the PV part and the T part, but a PVT standard per se to reduce the cost of a test and to tackle risks generated by combining the two technologies is still missing.

Research questions that are still to be answered are:

- TRL 9 levels are still needed for some PVT collectors with more demonstration plants monitored.
- Make the cost fall by a factor of 1.5 to 2 through volumes and/or technology improvements.
- Subsidy fair schemes for PVT collectors in all markets (Task 60 issued report D6 on this topic).
- Integrated standards that combine PV and T in one testing cycle at a reasonable cost for the manufacturer and when "minor" changes to the design are made.
- Labels for PVT solutions.
- Durability testing and feedback, especially for concentrating PVT.
- Optimization and best combinations deserve more work based on best practices.
- The advantages of the cooling effect on PV production and reduced lifetime performance degradation in a PVT collector, especially with heat pumps, deserve more work.
- Use of PVT in solar thermal cooling applications is still not developed, although attractive.
- Use of the PVT hardware at night to capture night sky radiation effects and the associated cooling applications is still not well developed, although attractive.
- System optimization like local use vs. grid injection, cold or hot storages combinations for large projects needs study cases.

- Reducing system costs through innovation and teaching is a topic, especially for PV-only or PV + heat pump solution.
- Simplifying installation is always a topic.
- LCA and recycling of PVT collectors deserve some attention, although not different from PV and T existing solutions.

Challenges faced by PVT industries are:

- Deciding on the right choice of materials to use in a PVT collector can be a challenge due to the thermal constraints the PV module must bear.
- Thermal system modeling and yield prediction are more complicated than for electricity alone.
- The limited number of validated system modeling cases makes it difficult for the supplier to quantify the advantages of PVT.
- The limited power of the PVT industry makes it difficult to influence standards and policies to favor PVT.
- The general awareness of PVT is still very limited among all types of stakeholders – homeowners, planners, policymakers, utilities and investors.
- Selling a complete system, which PVT somehow needs to make the most out of the combination of technologies, requires more effort than selling a PVT collector and more skills from the salespersons.
- There are some exciting emerging opportunities in the development of new low-temperature district heating systems, where temperatures less than 60 - 80°C are being trialed and promoted as the future choice for expanding the decarbonization of heating and cooling. This significantly enables PVT coupled with heat pumps to play a role in distributed and centralized solutions.
- Always being compared to PV is a situation that industries and distributors must be prepared to face with arguments and facts.

Opportunities faced by PVT industries are:

- Exciting policy setting opportunities will present with the New Green Deal in the EU. The PVT sector needs to be prepared to ensure that the case for PVT is heard and facilitated and not inadvertently excluded (as it was unfortunately in 2020 in Australia when renewable heat was not supported by policy).
- The European Commission on 14 October 2020 published its Renovation Wave Strategy to improve the energy performance of buildings. Deep renovations can improve energy performance by 60%. Again, an emerging opportunity to place PVT front and center of this initiative by being engaged as a body in this process (https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en).
- There are some exciting emerging opportunities in the development of the 4GDH (4th Generation District Heating) program where temperatures less than 100°C are being trialed and promoted as the future choice for expanding

the decarbonization of heating and cooling. This significantly enables PVT coupled with heat pumps to play a role in distributed and centralized solutions (https://www.4dh.eu/).

- Seasonal storage opportunities will provide PVT systems the ability to monetize more of the heat generated that may otherwise be lost due to curtailed production. For example, when the customer's summer PVT production exceeds thermal demand.
- Solar cooling is emerging as another area of great interest. PVT can contribute to these low carbon solutions with its diurnal heating features during the day and cooling during the night.

3 Potential

Energy that could be replaced by PVT systems will be important for meeting societies' needs for decarbonized thermal and electrical systems.

The range of production varies from 700 to 2500 kWh/kW for electricity and 100 to 700 kWh/m^2 for heat, depending on collector type, climate and application.

Assuming that a PVT installation produces in a mid-European climate, 1,000 kWh/kWp of electricity and 500 kWh/m^2 of heat, the 2019 savings from a PVT installation are about 270,000 MWh of electricity and 1,000,000 MWh of heat, which corresponds to about 100,000 toe (tons of oil equivalent).

If the PVT market grows by 10% each year, starting from a base of 2 million m^2 in 2018, it can be assumed that 40 million m^2 will be sold in 2050. This would be 20 times the current market volume and represent a significant part of the solar thermal market (around 180 million m^2 in 2020).

We can even take this a step further. There is no PV roof without PVT collectors if the owner runs a heat pump in the building! Especially in dense areas where air heat pumps are considered to be too noisy and borehole drilling can be limited.

Cooling needs will continue to increase in the coming years. This represents an opportunity for PVT collectors because they can 1) produce electricity for the operation of a compression chiller and 2) be used to reject heat to the environment via convection and heat radiation. This additional function as a heat sink will also increase the competitiveness of PVT.

Other applications in the agriculture and process heat segment will develop.

See also Task 60 wiki page:
https://en.wikipedia.org/wiki/Photovoltaic_thermal_hybrid_solar_collector

4 Actions Needed

Challenge	Action needed
Increase governments' awareness of PVT solutions: PVT is an attractive alternative to PV and T solutions and to air or ground-sourced heat pumps.	Targeted dissemination of SHC Task 60 results and reports.
Propose clever and fair subsidy schemes for PVT collectors and systems to governments and support their adoption.	SHC Task 60 issues recommendations, namely to improve the situation in France, and Task participants continue to work with national solar energy associations to promote improved schemes in their countries.
Increase architects' awareness of PVT solutions – PVT is more efficient than just PV.	Researchers and industries should attend more conferences to present successful solutions and publish articles in relevant magazines.
Increase planners' awareness of PVT solutions that PVT can be more cost effective than any other solar solutions, especially for some applications like hotels.	Articles in technical magazines, teaching seminars, and testimonials of leading planners in the field should be undertaken by the PVT industry.
Increase installers' awareness of PVT solutions – PVT is as easy to install as PV and T solutions.	Articles in journals – demonstration projects – video channels.
Increase engineering students' awareness of PVT solutions by giving classes and tools for simulation, such as the ones found on PVT collector providers' websites.	Develop teaching materials and dedicated classes on the topic.
Develop an appropriate standard on combined PVT testing so that all in one testing batch can be achieved and subsequent design changes can also be covered at a lower cost.	Continue SHC Task 60 work based on Task report, Status Quo of PVT Characterization, with ISO and Solar Keymark.
Develop Solar Keymark certification for PVT.	Annex P5.1 of Solar Keymark is in place and should be more widely disseminated with the help of SHC.
Reduce PVT collector costs and ensure that they are as durable and easy-to-install as PV-only collectors	PVT industry + research needs financial support for innovation.
Make PVT systems cheaper and simpler to install.	PVT industry + researchers need financial support for pilot and demonstration projects with monitoring and results communicated.
Increase the number of available PVT best practice examples.	Survey campaigns in several countries or at the IEA level, see also the Task 60 website and Task report, Existing PVT Systems and Solutions.

Increase automation in PVT industry so that the cost of producing collectors can be reduced without giving up quality and durability.	Expand public support and market development.
Inform PV and heat pump industries about PVT's possibilities as a heat source and train their installers.	More articles and communication. Meet them in fairs and conferences and disseminate best practices and cost-effective cases.
Use KPIs based on testing and not just simulations when promoting PVT solutions to ensure the evaluation is reliable and relevant and to increase customer and planner confidence.	Some test labs must be made aware of PVT global testing and the industry should rely more on them.
Use common notations and KPI's for communicating research and field results so that comparisons are possible between different manufacturers and planner offers.	Disseminate the relevant SHC Task 60 reports.

5 Appendices

5.1 PVT Markets in 2019 (from Solar Heat Worldwide, Ed. 2020)

Country	Water Collectors [m²]			Air Collectors [m²]	Concentators [m²]	TOTAL [m²]
	uncovered	covered	evacuated tube			
Australia	523	0	0	24	0	547
Austria	595	922	0	0	0	1,517
Belgium	712	0	16	290	15	1,033
Brazil	26	0	0	0	0	26
Chile	213	101	0	0	10	325
China	133,721	50	0	0	171	133,942
Denmark	85	0	0	0	0	85
Ecuador	0	4	0	0	0	4
Egypt	0	0	0	0	21	21
France	12,619	68	0	471,900	0	484,587
Germany	110,622	1,452	0	87	165	112,326
Ghana	8,000	0	0	0	0	8,000
Hungary	525	53	0	0	0	578
India	0	7	0	0	255	262
Israel	57,488	0	0	0	0	57,488
Italy	13,331	2,170	0	0	0	15,501
Korea, South	280,814	0	0	0	0	280,814
Luxembourg	635	0	0	145	0	780
Macedonia	260	74	0	0	0	334
Maldives	0	0	0	0	21	21
Netherlands	30,353	0	0	0	1,773	32,127
Norway	267	0	0	0	0	267
Pakistan	0	7	0	0	0	7
Paraguey	0	0	0	0	51	51
Portugal	335	0	0	0	0	335
South Africa	0	0	16	0	751	767
Spain	1,552	11,350	0	0	0	12,902
Sweden	0	0	0	0	31	31
Switzerland	7,720	36	0	3,530	0	11,286
United Kingdom	851	312	229	348	0	1,740
United States	5,400	0	0	0	0	5,400
Uruguay	0	2	0	0	0	2
Other	529	3,240	16	0	0	3,785
TOTAL	667,178	19,846	277	476,324	3,263	1,166,888

Table 2: *Total installed PVT collector area worldwide. (Source: IEA SHC Task 60 survey, AEE INTEC)*

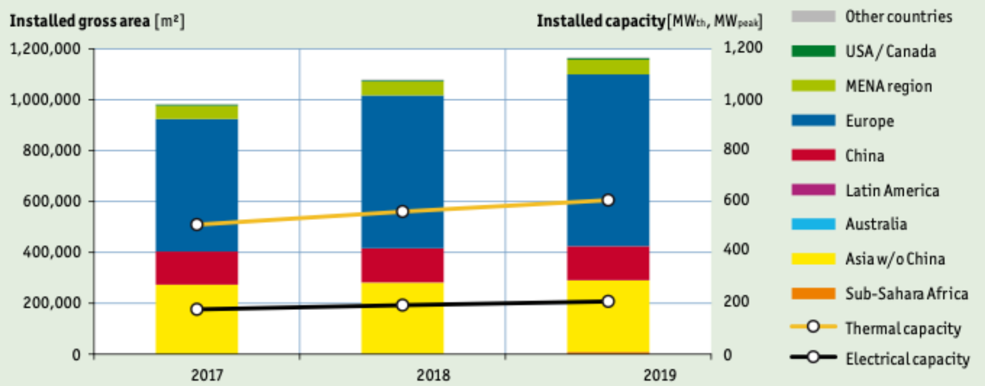


Figure 14: *Global market development of PVT collectors from 2017 to 2019 (Source: IEA SHC Task 60 survey, AEE INTEC)*

The following figure shows the total installed collector area and the distribution by PVT technologies by country in 2019 in Europe.

By the end of 2019, the total cumulative thermal capacity of PVT collectors was 606 MW_{th} and the PV power was 208 MW_{peak} installed worldwide. With a global share of 55% of installed thermal capacity, uncovered PVT water collectors were the dominating PVT technology produced, followed by PVT air collectors with 43% and covered PVT water collectors with 2%. Evacuated tube collectors and concentrators play only a minor role in the total numbers.

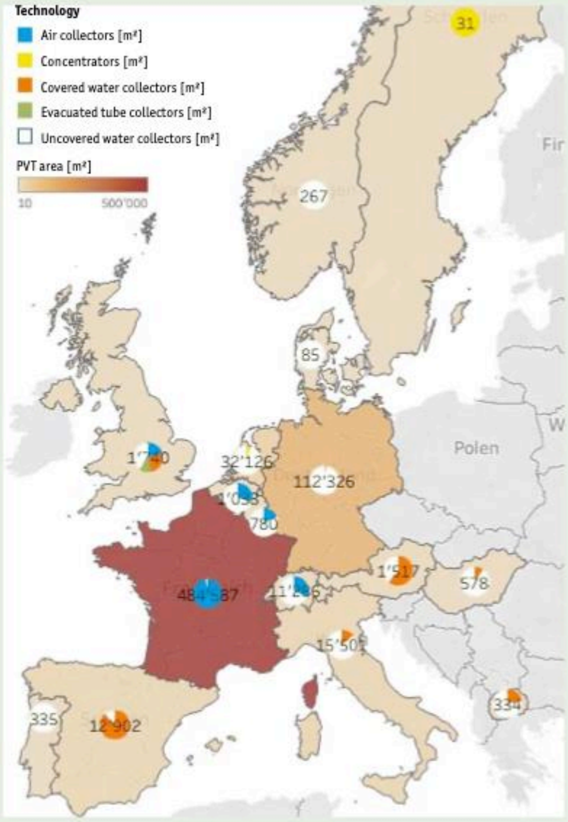


Figure 15: *Total installed collector area and PVT technology in Europe at the end of 2019. (Source: IEA SHC Task 60 survey, AEE INTEC)*

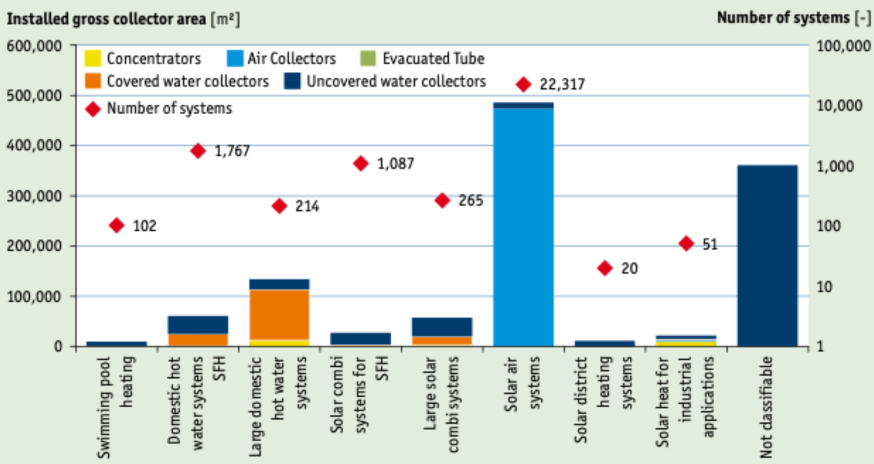
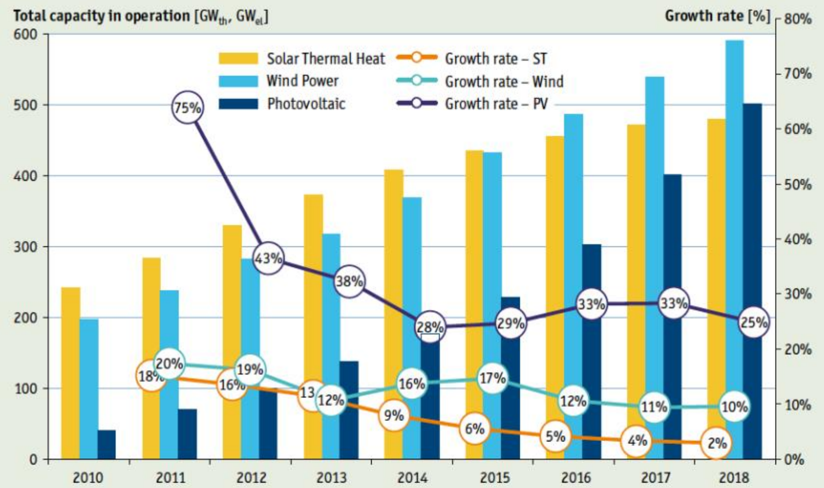


Figure 16: *PVT systems in operation worldwide by application, collector type and collector area at the end of 2019. (Source: IEA SHC Task 60 survey, AEE INTEC)*

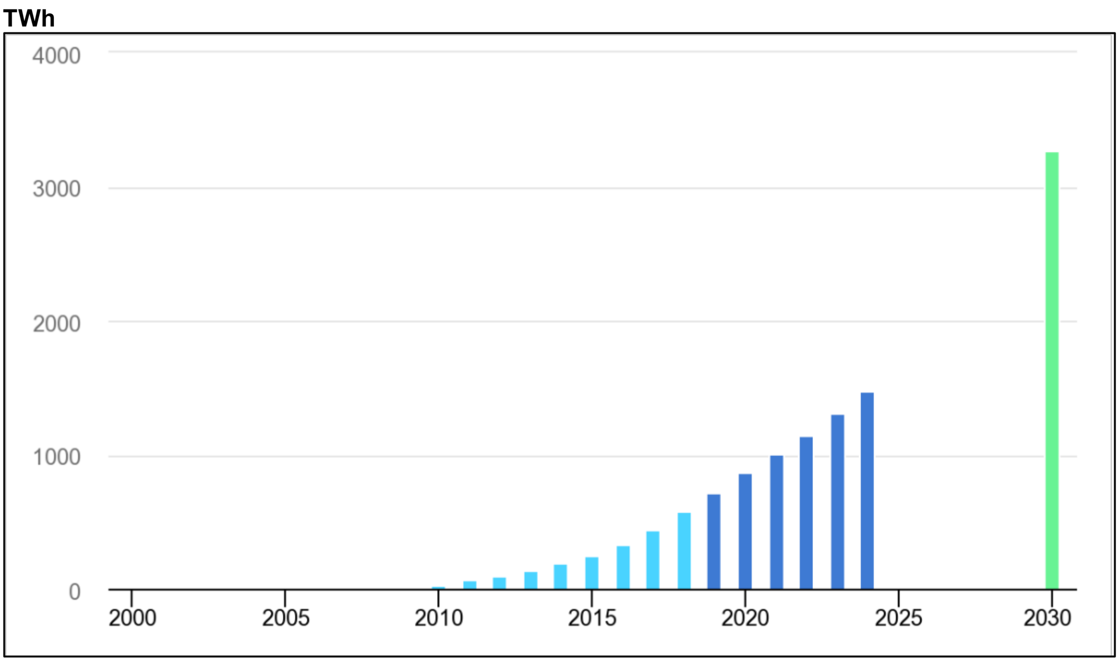
5.2 PVT Development Forecast



Global capacity in operation and market growth rates between 2010 and 2018

(Sources: AEE INTEC, Global Wind Energy Council (GWEC), European PV Industry Association (EPIA), REN21 - Global Status Reports 2011-2019)

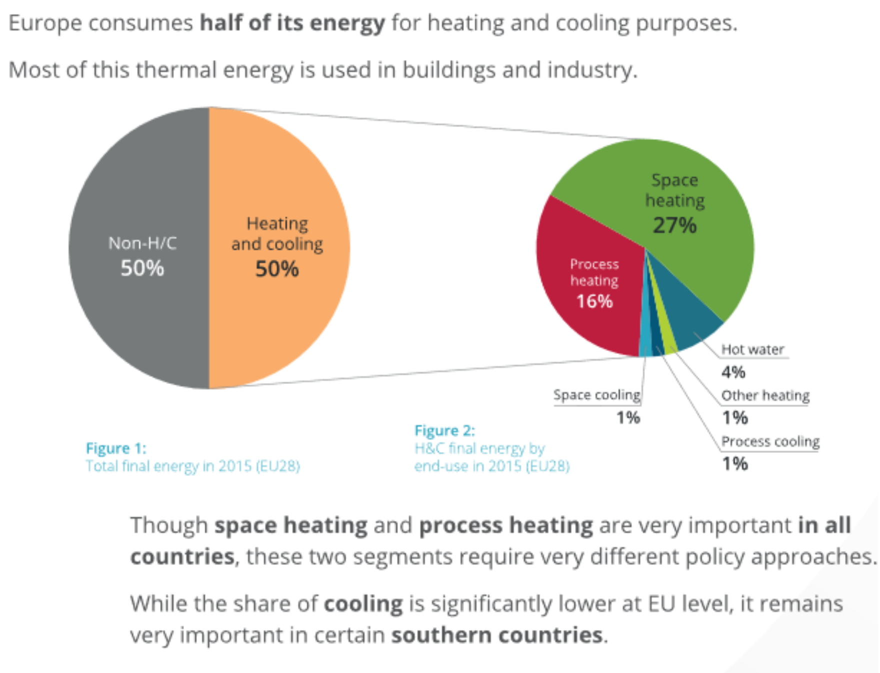
Growth curves of PV and T as forecasted. IEA SHC Solar Heat Worldwide 2020



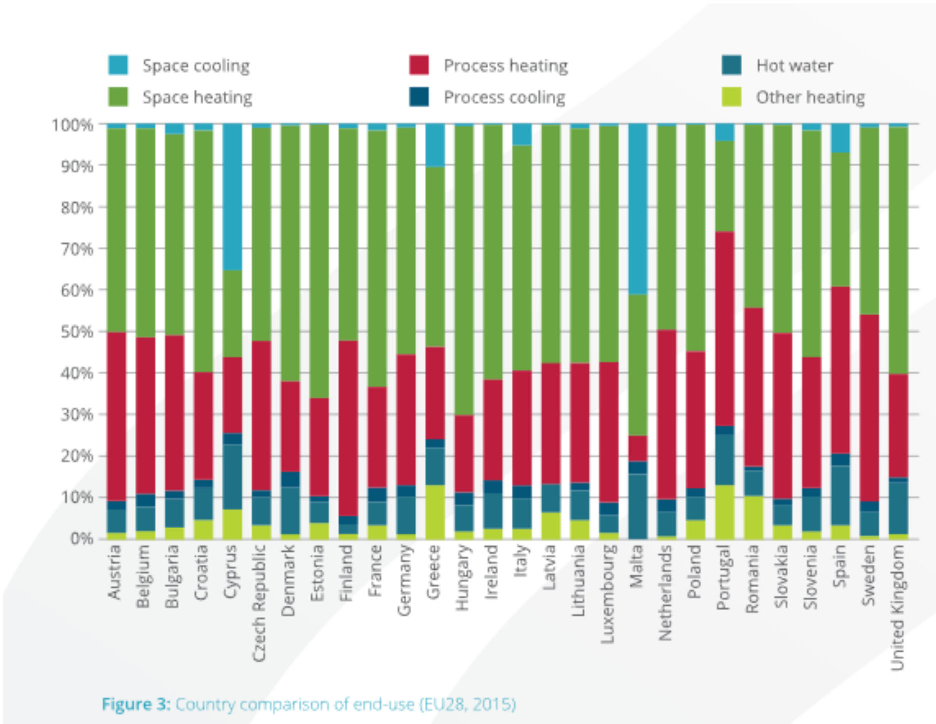
Solar PV power generation in the *Sustainable Development Scenario, 2000-2030*. IEA January 2020

5.3 Market Potential – EU28

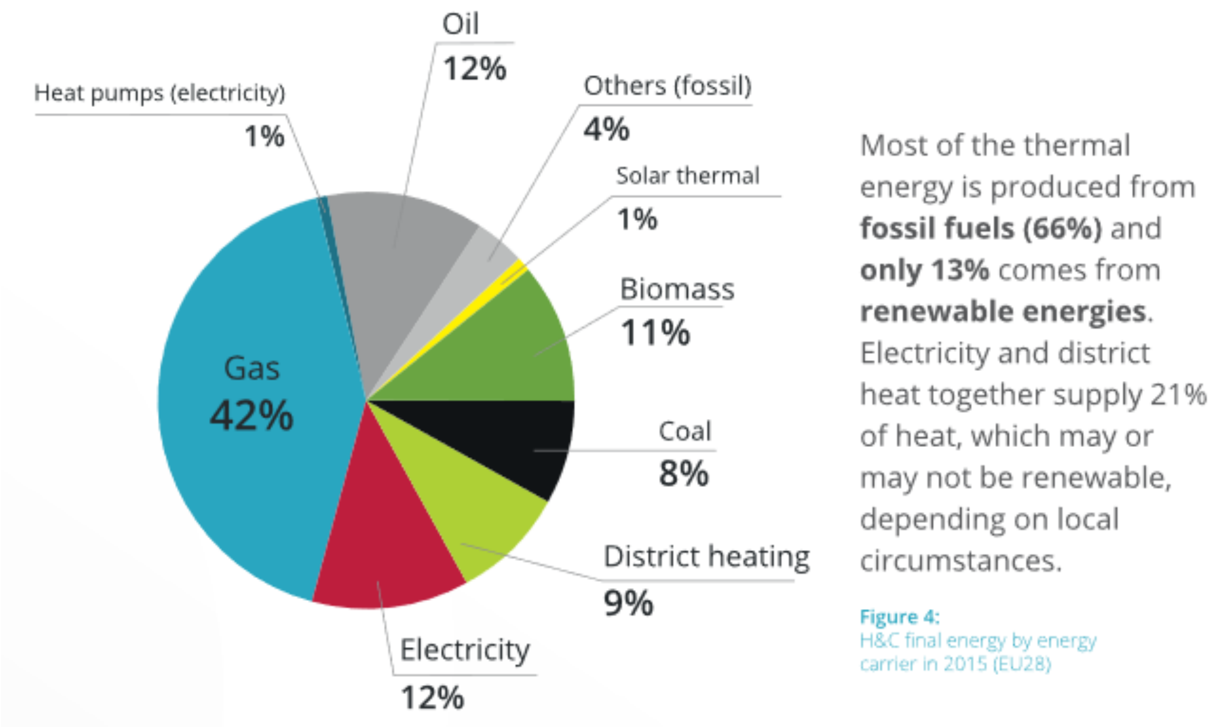
Source: https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cce/2017/29882_Brochure_Heating-and-Cooling_web.pdf



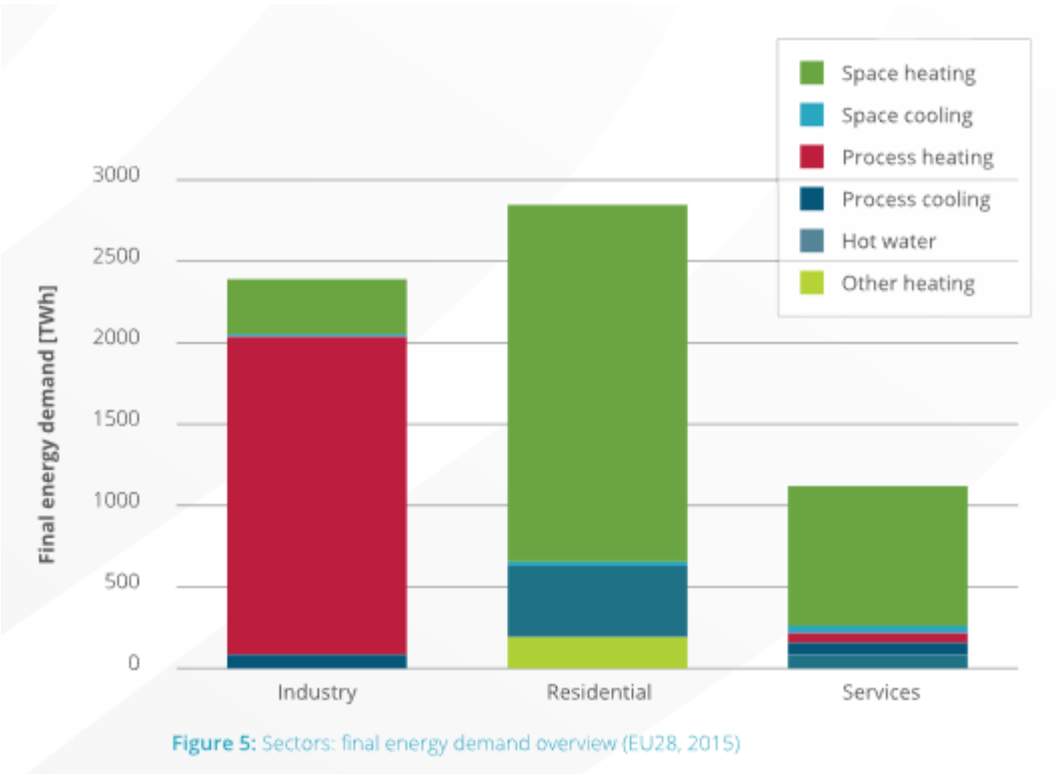
Heating and cooling as a portion of final energy demand. 2017 Heat Roadmap Europe 2050



Heating and cooling as a portion of member states' final energy demand. 2017 Heat Roadmap Europe 2050



The portion of energy carrier in heating and cooling final energy demand in 2015 (EU28). 2017 Heat Roadmap Europe 2050



Heating and cooling across the sectors as a portion of final energy demand. 2017 Heat Roadmap Europe 2050

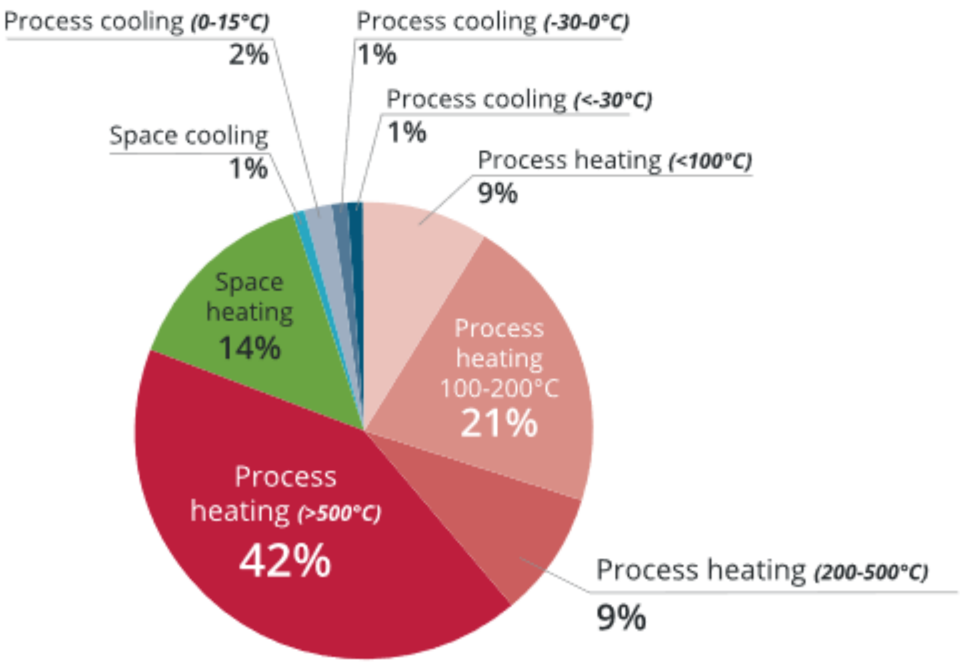


Figure 6: Industry final energy demand end-use (EU28, 2015)

Heating and cooling thermally segmented requirement as a portion of final energy demand for the industrial sector. 2017 Heat Roadmap Europe 2050