Market Activation and Standardization of Plug-in Solar and Storage (MASplug)

Best practices for plug-in photovoltaics: what second-movers can learn from a first-mover

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Preface

Imagine the year 2030: For just a few hundred euros, anyone can buy two solar panels, an inverter, a mounting structure, and cables, which they can install themselves – without an electrician – at home. Just mount the system on a balcony, a roof or in your yard and plug the cable into a power socket. Practically everyone, even those who cannot make decisions about their own roof, will be able to participate in generating clean energy even as they save money. What's not to like?

These systems will be ubiquitous: People will get them online and at retailers like Aldi, IKEA, and their local DIY hardware store. Savvy customers will still, however, purchase them at specialist shops, where staff can better answer questions about the technology.

This situation already describes Germany well, but the number of countries is growing. One may therefore be tempted to sit back and relax because the market is coming anyway, but first-mover markets like Germany show three pitfalls.

First, while plug-in photovoltaics (PIPV) is often called "balcony solar", the systems are still mainly installed in yards of single-family homes and townhouses in Germany. The reason is simple: These people can do what they want. In contrast, those who live in apartments – even those they own – generally have to get permission from property management when installing PIPV. Up to 2024, these facility managers in Germany were able to block PIPV on balconies because the panels changed the building's appearance or because of safety concerns (often both). Since 2024, PIPV has been "privileged" under German law, and Germany also addressed safety issues with the world's first PIPV standard adopted in December 2025. And yet, the press still frequently reports that property managers refuse PIPV. Granted, affected households will win in court, but the challenges cause headaches, costs, and delays. Even with proper legislation, awareness campaigns are needed.

Second, standards experts across the globe are now working on their own PIPV rules. They frequently conclude that a dedicated circuit for PIPV, one with no other appliances on it, would be safest. They are correct in theory but wrong in practice. A dedicated circuit for PIPV is indeed safer, but the result of requiring an electrician to install a new power circuit to the fusebox will not be safer PIPV. Instead, households will refuse to spend more than a thousand euros for an electrician (if you can even get one) to install a new circuit for a PIPV system that only costs hundreds. PIPV will then continue to be used primarily by homeowners, who do not have to ask property management for permission. The potential for the technology's sweet spot – apartments - will remain untapped. And if "balcony solar" becomes "guerrilla solar", people might concoct truly unsafe system configurations on their own. The benefits of PIPV far outweigh the manageable amount of risk. In other words, the result of a standard requiring an electrician would be safer compliant systems, but more plentiful non-compliant ones.

Finally, batteries are now included in PIPV packages more often than not. Regulators did not see this market of small plug-in storage coming (to be fair, few did). As a result, these systems are often left out of price signals for grid support. Here, Germany is a laggard; other countries have already gone further along in integrating households in grid support. Now, all countries need to include plug-in storage in their scope.

The main benefit of PIPV is easily overlooked: a change in mindsets. We all know people who drive ten minutes to save a few cents on gasoline. Never mind that the savings might not offset the extra expense of driving more – most drivers roughly know the price of gasoline that week, and many act upon that information. Electricity consumers? Not so much.

PIPV with storage will bring displays of current electricity consumption and dynamic power prices into homes. People will willingly adjust their behavior accordingly, with automated systems doing the heavy lifting. This alone will fix so many problems.

Finally, “plug and play” only applies to the equipment. Many factors in the real world make it hard to install PIPV: you have to find an electrician, understand electricity rates, get permission from building management, possibly contact support, etc. As Marine Cornelis of Next Energy Consumer puts it: "This is precisely where the energy transition will be won or lost." Policymakers are called on to remove unnecessary barriers, which are described below.

This white paper presents the case of Germany as a first-mover and draws conclusions adapted to second-mover countries. To ensure transferability, the German Association of Plug-in Solar (Bundesverband Steckersolar or BVSS) and Anker SOLIX, a manufacturer of PIPV, asked experts in each of these countries to review the paper and help design recommendations for their countries. These experts are listed in the Acknowledgements. We are grateful for their time and effort. Any errors remain ours.

Anker SOLIX and the BVSS

Two panels tilted on a balcony in Germany for better orientation. Photo: Sebastian Müller.

Acknowledgements

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Disclaimer

All prices used in this document are from the spring of 2026 and are meant as approximations.

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An inconspicuous (see if you can spot it!) single plug-in solar panel on the historic Town Hall in Freiburg, Germany. Heritage buildings are often off limits for plug-in solar, but not always. Photo: Sebastian Müller.

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Recommendations

1. Create PIPV standards without unnecessarily requiring electricians. What makes PIPV affordable and special is that people can do it themselves: power generation as appliances.
2. Electricians should be consulted if there are any doubts about a household's PIPV-readiness. Do not install PIPV if your sockets look suboptimal, your wires are very old, or if you do not have modern circuit breakers.
3. Run any and all upfront subsidies through a central PIPV registry. People will register if they feel they are signing up for their bonus.
4. The product standard should include a machine-readable data sheet (QR code, etc.) that people can upload to the registry so that laypeople don't have to answer questions about technical matters (watts, etc.).
5. Prepare for batteries with interfaces for grid communication. New systems will adjust output based on grid needs. Distribution grid operators should provide grid price signals for plug-in storage.
6. Prepare for current monitors. They will provide greater safety by adjusting power injected into the home based on what circuits can safely handle. Standards are needed here, however.
7. Adopt a right to install: PIPV does not affect the building it is installed on any more than a parasol does. Property management must have good reasons for refusing permission – simple aesthetics does not suffice.
8. Create campaigns for apartment complexes. PIPV will not happen automatically outside of single-family homes and townhouses. Property management needs to see PIPV as the first step in building-wide energy refurbishment.
9. Provide a "one-stop" info center for PIPV: whenever laypeople are encouraged to engage in a sector like energy usually reserved for specialists, a central explanatory website with a phone and email hotline can be useful for questions that inevitably arise.

A panel tilted on a balcony in Poland showing the mounting system. Photo: OneStep.Solar.

What is plug-in photovoltaics (PIPV)?

PIPV allows everyone to plug a small solar power generator into a conventional household power socket to generate their own solar electricity behind their fusebox. Because household circuits have quite limited capacities, these systems are generally small, but there is currently no international size limit that defines such units as distinct from rooftop arrays.

Indeed, PIPV can be installed on roofs. It is also frequently installed in gardens (ground-mounted), terraces, and balconies. Because it has become so popular on balconies, PIPV is popularly referred to as "balcony solar." It has also been called "guerrilla solar" because the technology does not neatly fit the rules for rooftop solar, often leaving PIPV in a legal grey area. One aim of this white paper is therefore to help policy-makers clarify the status of PIPV.

Energy literacy is the biggest benefit of PIPV.

The point of connection for PIPV units distinguishes them from other solar arrays. Solar rooftop systems are generally connected directly to the grid by an electrician using a dedicated circuit breaker and a special plug with pins that are not exposed (the plug is usually fixed permanently anyway). It is not legal for anyone without an electrical license to make such connections. This solar power passes into the home via the breaker box just as conventional electricity from the grid would. In contrast, PIPV needs no electrician, can use a standard power plug, and generates power inside the home; the fusebox and power meter see the electricity from PIPV as lower demand – as though appliances had been turned off.

A PIPV system consists of:

- ♦ one or more solar panels,
- ♦ a DC cable (solar cable) connecting the panel(s) to the inverter,
- ♦ the inverter, which converts the direct current from the panel(s) into the alternating current (AC) common in household circuits,
- ♦ an AC power cable, which is usually simply the standard residential electrical cable, though special cables are available for this purpose (Wieland and Seplugs in particular), and
- ♦ a mounting system for the panels depending on the specific case (ground, balcony, roof, etc.).

Storage units are a popular add-on for PIPV, with roughly 70% of systems currently sold with these in Germany. These batteries increasingly include Home Energy Management software (HEMS) that can tailor charging and discharging to individual consumption, but also to local distribution grid needs, which in turn increases the amount of solar power the grid can absorb.

Why PIPV?

As with other building-integrated solar, PIPV:

- produces clean electricity;
- takes up no additional space (no conflict with farmland or nature preservation);
- helps people lower their power bills; and
- prevents the need for expensive grid expansion by providing power exactly where it is consumed.

But PIPV goes further:

- Because no electrician is needed, small systems become affordable, so more low-income households can participate: a (larger) roof array generally costs thousands, whereas a (smaller) PIPV system costs hundreds.
- Households that share a roof (whether renters or owners) and cannot reach a joint decision about a roof array can usually still install a small system on their terraces and balconies.
- It is also more appropriate for renters as the equipment can be removed easily. If the owner of the system leaves the property they can take it with them.

What's more, PIPV with storage can help people manage their power consumption using Home Energy Management Software (HEMS) often included in batteries. Here, mindsets begin to change: People will think about fluctuating power prices as much as car drivers think about the price of gasoline.

And then there is resilience: During a power outage, a base level of power supply can be provided if the system has an off-grid mode (see below). In most upper-income countries, the electricity from PIPV will not be enough to power the entire households as from the grid, but it should be enough to power a refrigerator, cell phones, a radio, and a few lamps.

A balcony in Germany with three panels titled on the railing and three retractable panels connected to the ceiling that can be used as an awning. Photo: Sebastian Müller.

Potential of PIPV

The benefits of PIPV listed above are largely social. What is the potential of PIPV in overall power generation and climate change mitigation?

Perhaps the best estimate comes from Switzerland. A study puts the potential power generation from PIPV at 894 GWh/a to 1,040 GWh/a. The country consumed 53,476 GWh of final energy in 2025, putting the potential from PIPV at just below 2% – in line with BVSS estimates for most countries.

That figure might seem low, but research has underscored the bandwagon effect of PIPV: once one home has PV, neighbors start to install it. The number of visible solar panels in close proximity (within 100 meters) to someone's home has even been found to be more influential than exposure to the topic on social media – especially in low-income neighborhoods.

Energy literacy is the biggest benefit of PIPV. As the technology spreads, more people will begin paying attention to their electricity consumption. Already, PIPV systems can display power generation across the day at a resolution sufficient to depict passing clouds on a smartphone app. As batteries and Home Energy Management Systems (HEMS) become more widespread, people will have displays showing power consumption alongside generation. They will be able to adjust consumption to match generation, even remotely, for instance by switching appliances on and off – or the whole process will happen automatically: You leave home in the morning for work, and the house optimizes its own power consumption during the day. We talk more about this in the HEMS section below.

A PIPV system with two panels as a canopy over a porch at a cottage in Poland. Photo: OneStep.Solar.

Safety

Because PIPV is installed by laypeople, concerns have been raised about their safety. These concerns fall into two categories: wind and electrical loads. Users should inspect their PIPV systems at least once a year and before and after every storm to ensure that mounting structures are still in good shape (no loose screws, no clamps damaged, etc.) and that the panels have not been damaged. In the process, you can also wipe off the panels to remove dust that reduces power generation and makes the system heavier.

Making PIPV stormproof

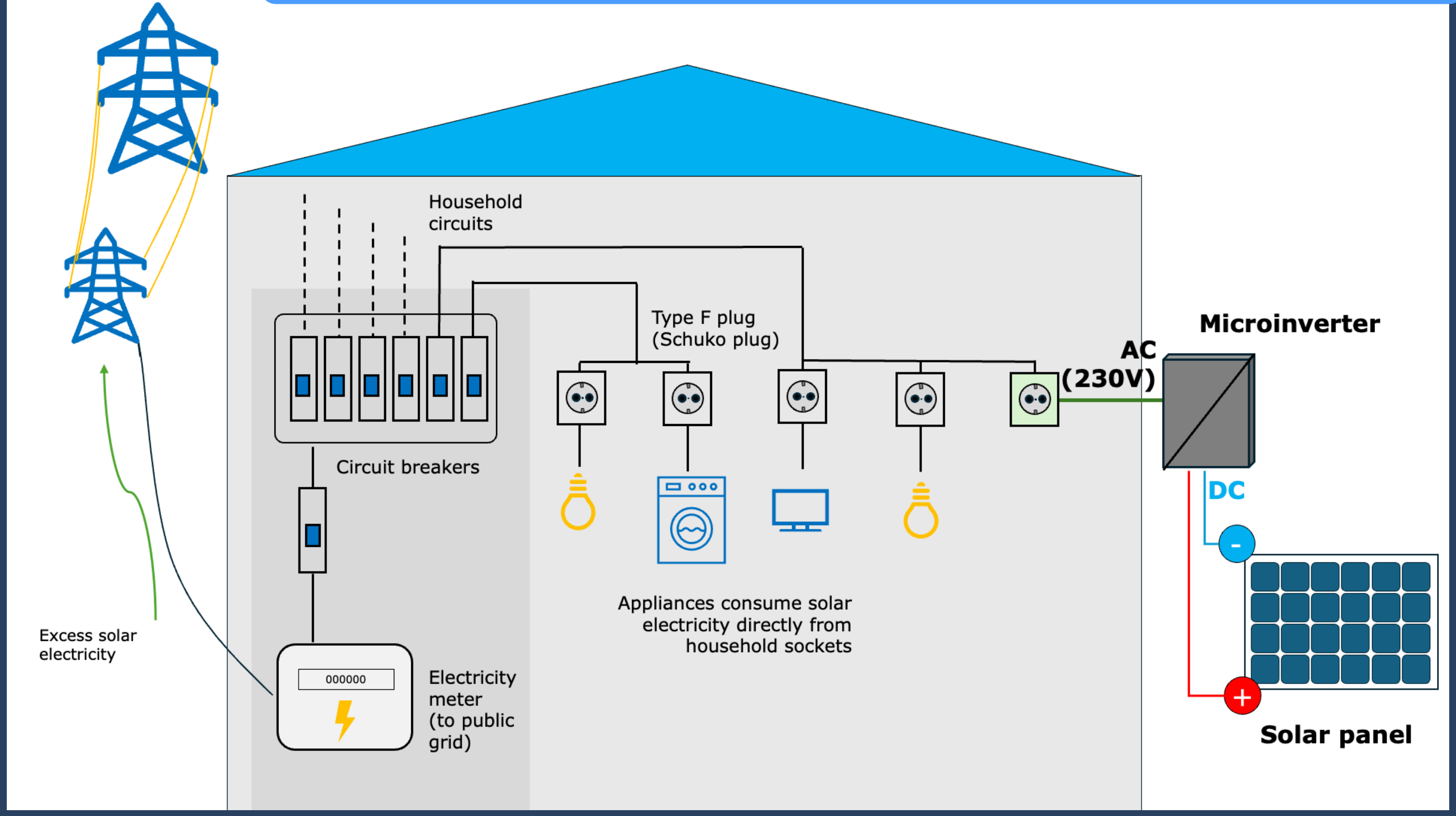
The rules for wind in Germany changed recently. Up to 2023, modules installed more than four meters above the ground had to be made from plastic, not glass. In 2023, the DIBt (German Institute for Building Technology) stipulated that balcony power plants are not construction products and therefore not subject to building regulations, specifically glass construction regulations. It is now up to the distributor of plug-in solar devices to define the exact location of use for their models.

In December 2025, the new German PIPV product standard stipulated that the wind and snow zone within which a PIPV product can be installed must be indicated on the package or in the manual. The height of the installation also plays a role as wind speeds increase with height. For homeowners with ground-mounted systems, these issues are less relevant. For

A diagram of a PIPV system in a household

The solar panel provides direct current (DC), which a micro-inverter converts into alternating current (AC). The AC enters a household circuit, to which other appliances are connected. The solar energy powers these appliances directly (here, a TV and light bulb), but appliances on other circuits behind the same breaker box (here, a washing machine and light bulb) are also powered from PIPV. Any excess electricity can be exported to the grid through the power meter (backfeed).

Some countries compensate for power exports; others don't. Some also prohibit backfeed without an electrician. Devices that prevent backfeed add to the cost, as does the electrician.



apartment dwellers (owners and renters alike), the challenge is knowing about these issues when making a purchase at a retailer whose staff are not specialists; speciality shops should provide advice on proper installation. However, property management can provide assistance in PIPV guidelines, as discussed below.

Importantly, residents are liable in cases of improper installation as they would be with air-conditioners, giant parasols, planters, and other things they set up/install themselves. Property management should require confirmation of proper installation so that liability lies clearly with residents.

For the EU, the rules for wind zones and buildings are set forth in “Eurocode 1: Actions on structures”, in particular “Part 1-4: General actions - Wind actions”. However, these standards are behind paywalls; laypeople will generally not have read them.

The burden of safety therefore falls somewhat on manufacturers of components, especially mounting systems and panels. But they cannot know everything about a given system’s location. Countries are divided into “wind zones”, and both manufacturers and laypeople can know which zone a system is to be installed in. However, a solar panel hooked onto an 11th story balcony will be exposed to significantly different wind loads than a panel installed on the first floor of the same building – the wind zone does not tell us everything.

Though a justifiable concern, in practice the issue is manageable. There have been no reports of PIPV panels falling off buildings in Germany, where more than a million units are registered.

Electrical safety

The electrical safety of PIPV centres on preventing electrical shocks and fires from overloaded power circuits in walls. Both of these risks are very low. We live with much higher risk levels from the lithium-ion batteries in smartphones, e-cigarettes, laptops, etc.

A study from 2025 found that 100 fires were caused by such batteries in the Netherlands with a population of 14 million. To date, there have been no recorded cases of electrical shocks from PIPV in Germany from more than a million registered systems,

Seplugs adds retracting sleeves over the pins to a standard European plug to provide touch protection without requiring a special socket. Photo: Seplugs.

but these hazards are important to address for the technology use to be kept safe.

Protection from shocks

The main two components with a risk of electric shocks are the power plug and the inverter, both of which are well accounted for in modern system design. Modern inverters (not only for PIPV, but all grid-attached solar) come with safety features that prevent shocks. Called anti-islanding, this function switches off power export from the inverter within 0.2 seconds if normal grid parameters are not detected. Defective inverters can, however, cause shocks, such as when capacitors leak, but this risk is very low.

The use of standard household plugs breaks a principle for standards experts. Generally, the pins of such plugs are exposed, meaning that they can be touched. Plugs for power generators have covered pins that cannot easily or accidentally be touched. Using protected plugs along with an inverter with anti-islanding is the belt-and-suspenders approach for PIPV.

As backup protection, some experts recommend special plugs. One option is to add a cover to the pins on a conventional plug. This approach is practical because the wall socket does not need to be changed. Seplugs, for instance, surrounds the pins on a Schuko plug (common in most EU countries) with a sleeve that retracts back into the plug's housing when the plug is inserted into a household socket.

The Wieland plug is another option. It also completely encloses the pins but requires a special socket. Only electricians are allowed to perform work on power sockets. So while the plugs and sockets themselves may not be expensive, the cost of an electrician installing a new socket will add hundreds to the cost of PIPV.

In conclusion, the safety provided by the anti-islanding function already included reduces risks from PIPV.

Protection from circuit overloading

Power cables heat up over time when under heavy loads. One example is chargers for electric cars for household power sockets: While the wiring inside the home is rated to handle 16 amps in Europe, the chargers themselves generally only draw 10 amps. Thus, the cars only draw just under two thirds of the wire's capacity. As the charging usually takes around 12 hours, it is important to avoid sustained maximum loads on wiring, lest overheating wires cause fires.

Overloaded wires result from a mixture of peak loads and heavy loads over time. Unfortunately, setting proper limits is not so easy. Circuit breakers generally prevent excessive peaks, but only when excessive loads are detected; we will come back to this issue below. But first, let's take a look at the German limits on PIPV system size to understand the issue of heavy loads over time better.

Germany has the world's first standard for PIPV, and it sets three limits on system size:

- ♦ 800 VA AC from the inverter,
- ♦ 960 W DC from the panels and
- ♦ 2,000 W DC from the panels with “special protection”.

The 2,000 watts DC also run through an 800 VA inverter. The extra solar power DC simply means that the 800 VA AC is available for longer periods. Given that Germany has a strong reputation in electrical engineering, you might be tempted to assume that these numbers are based on limits found to be practical or safe in tests. They were not.

A misconception emerged and spread that a limit of 800 W from a 2016 EU regulation could apply for PIPV. The misconception then became law when lawmakers adopted the limit for a lack of other baselines. The regulation stipulates that generators larger than 800 W in capacity were not “significant” for the grid at voltages below 110 kV. Logically, micro-generators smaller than 800 W would then be considered “insignificant” for the grid, so limiting PIPV to 800 W seems to make sense. But actually, this EU regulation is talking about something else.

First, 110 kV is the lowest voltage level considered high voltage in Europe. Medium voltage is between 10 and 30 kV. Homes connect at 0.4 kV or 400 volts. PIPV is much smaller.

Second, PIPV is connected to household wiring, not directly to the grid. An 800 W PIPV system thus does not feed 800 W into the grid. Rather, it first offsets power consumption within the home. Only excess solar power is exported to the grid. In Germany, no compensation is paid for this excess from PIPV,

A parklet with a solar panel as a roof for customers. The electricity was used by the café that owned the parklet. Photo: Sebastian Müller.

giving PIPV an incentive to consume all of their solar electricity (zero backfeed). With batteries, zero backfeed is generally possible. The grid then perceives this household as having much lower power consumption, not as one that generates solar power.

So the 800 VA limit for PIPV inverters in Germany was adopted from the 800 W limit for grid significance from Brussels out of convenience. Is the 960 W limit for panels more justified? Not really: Here, a standard 20% markup was applied as usual for conventional PV. Because panels frequently generate less than 100% of their rated output, slightly smaller inverters run more often at high efficiency if their capacity is slightly smaller than that of the panels.

The 960 W limit is unfortunate from a market standpoint because few panels have a rated capacity of 480 W. One more frequently finds 450 W and 500 W panels. A 1,000 W limit would have been better in practical terms as it would have allowed consumers to purchase two 500 W panels. (The BVSS advocated for the addition of another option: no DC limit is needed if a lower safe AC limit of, say, 600 W is kept – see below.)

Granted, German households can still purchase two 500 W panels – even four, if they have the space. The upper limit is 2,000 watts for panels, but anything above 960 watts requires "special protection". Essentially, this protection is the belt-and-suspenders approach: anything up to 960 watts can use the standard German plug, but a special plug (not further defined) is required for the 961 to 2,000 W range.

What do German firefighters say about PIPV?

In 2023, the German Association of Firefighters reviewed risks from PV, including plug-in solar. Their finding: "The committee is not aware of any fire risks." Their only concern was that panels on balconies not block space for ladders in case residents need to be rescued from the balcony. They recommend that one meter of space be left.

The 2,000 W limit is not based on any safety studies either. Rather, Germany's Renewable Energy Act (EEG) had defined PV array sizes by panel capacity before PIPV arrived. Thus, lawmakers had to define the size of PIPV in terms of panel capacity, not just inverter capacity, for PIPV to fit in with the logic of the EEG. The law was passed in 2024, a year and a half before Germany's standard had been adopted. In setting the limit generously at 2,000 watts, lawmakers were making space for the standards experts to set the actual limit; legislators did not feel they had the expertise to set a lower limit of, say, 1,000 watts lest the standards experts were later to determine that a higher limit of 1,200 watts was safe. By setting 2,000 watts as the limit, German lawmakers got out of the way for electrical experts to make a final determination.

To provide compliance with the law, the German standards body then also adopted the 2,000 watt limit, albeit with special protection requirements. In reality, the panel size is less crucial than the inverter's capacity in any case; 2,000 watts of panels still can only produce 800 watts of AC for the home. However, a system with larger panel capacity produces 800 watts for a longer period of the day. The question is then how long it takes an 800 watt load to become a safety risk. We will look at one German study that attempted to provide an answer.

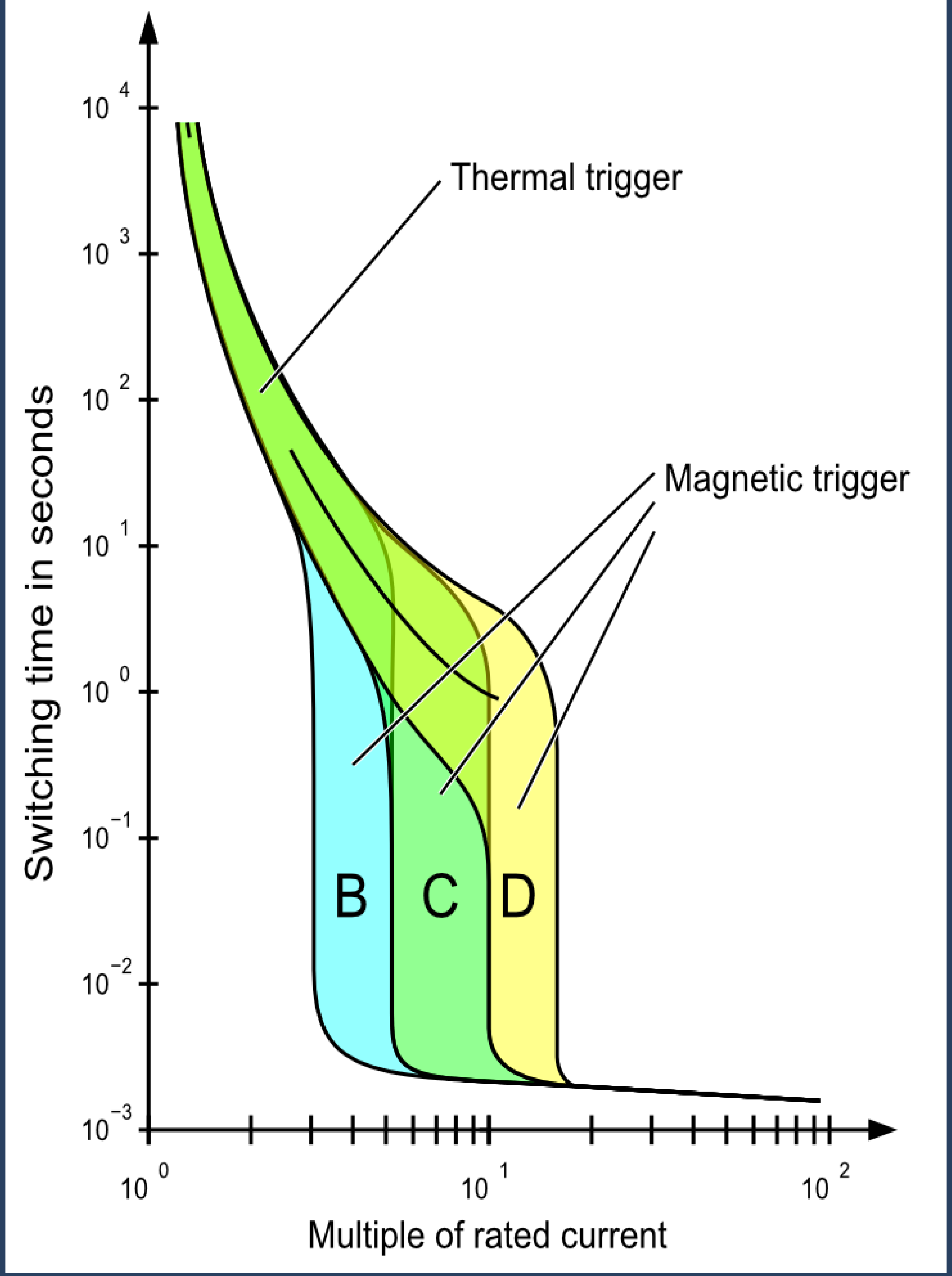
But before we continue, one conclusion for this discussion of maximum PIPV size is that the German limits are random enough not to serve as a model for other countries to copy. The German limits, however, have proven to be safe in the field.

Modelling household situations for PIPV safety: two studies

In a German study from 2017, researchers found that PIPV was safe up to 734 W. (This number is never cited in the paper but can be derived from the first sentence at the top of page 2: "Critical temperatures were not reached until the plug-in device reached a feed-in current of 3.2 A." Multiplied by the 230 V in German household lines, 3.2 A results in 734 watts.) At the time, the size of inverters was limited to 600 W, but the limit was increased by law in 2024 and in the standard of 2025 to 800 watts. Why did Germany allow for larger PIPV inverters if their current risk level had been proven to be non-zero in 2017?

The 2017 study modelled various scenarios. There were two main variables: the type of wire installation and the assumed electrical current in the household. The first variable concerns how wiring is laid inside the wall: surrounded by insulation (more heat build-up) or surrounded by air (more heat dissipation). Other cases in-between these two extremes are

As this chart below shows, the risk of fire is the product of current over time.



common and were also modelled, but it is important here to remember that homeowners generally do not know how wires are laid inside their walls, nor would they easily be able to make changes. Assuming the worst case thus seems justified to be on the safe side.

The specific thickness of the wiring also affects thermal performance, as does the material used (aluminum is common, copper not unknown in Germany). However, these factors are as unknown and hard to change as with the type of installation.

The second variable is the current in the circuit. There is a nominal current of 10 A, meaning that 10 A x 230 V or 2,300 watts is flowing. The first test current was then set at 113% of that to take account of the 13% tolerance, producing roughly 2,600 watts. Finally, the second test current of 145% is the level where the breaker trips after one hour to prevent overheating.

These power levels were sustained for 24 hours, and PIPV was added on top. With the exception of an EV charging at home, such sustained high levels of current are highly unusual in households. Rather, power-hungry appliances like hairdryers and washing machines run for a few hours, if not minutes.

In the end, the 2017 study focused on demonstrating the safety of the 600 watt inverter that was standard for PIPV at the time. The finding about 734 watts was almost an aside: by the way, the risks only start increasing at 734 watts from PIPV. Otherwise, the paper stressed that PIPV at 600 watts increased the risk of fires in homes by 0.00023%. Five million units would be expected to cause one death every 95 years. For comparison, fires caused by cooking stoves cause 470 deaths from fires in the US annually.

Germany has the world's first limits on PIPV system sizes, but the world should not rush to copy Germany's numbers.

When the limit on PIPV inverter size was increased by law in 2024 from 600 W to 800 W, a second study was published investigating the new situation. The maximum panel output has also been defined for the first time at 2,000 watts. That peak level would be throttled to 800 watts by the inverter, but larger panel capacity would mean that the 800 watts would be sustained for a longer time each day.

Instead of applying only a sustained load over 24 hours, the 2025 study was also based on a model of a standard household load, with peaks and valleys. Like the 2017 study, it modelled a 113% sustained load and found that 800 W of PIPV panels would "theoretically regularly lead to an overload of 21.6 A" (see page 4), with 2,000 watts of panels even overloading the line some 1,000 hours a year or several hours a day. However, this scenario is highly unusual.

Once the standard daily load was applied, PIPV "did not significantly increase" peak loads (see page 6) or raise wiring temperatures significantly. It concluded that the new 800 watt limit "does not compromise safety at all."

A balcony PIPV ensemble facing two directions to spread power generation across the day and make the best use of available space. Photo: Christian Ofenheusle.

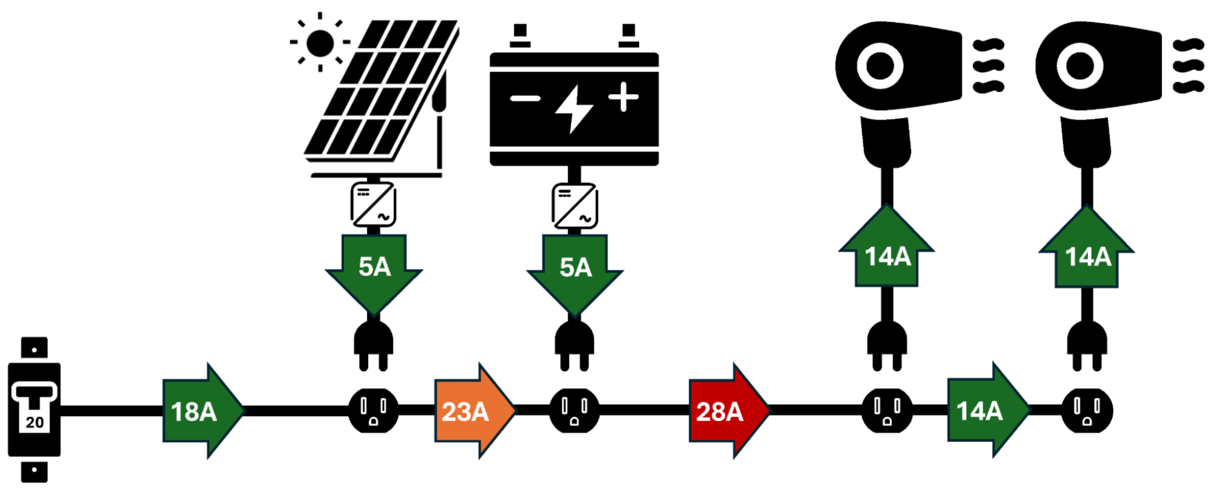
Panels installed on balconies generally do not leave behind any marks on the building when removed. The same cannot be said for panels installed on roofs or facades, as shown above. Here, holes have been drilled into the facade, which can lead to water damage; the facade protects the building from the elements.

Tenants will generally be prevented from installing panels on facades, but homeowners with no property management to oversee them should be careful not to damage their building when installing PIPV. Photo: Christian Ofenheusle.

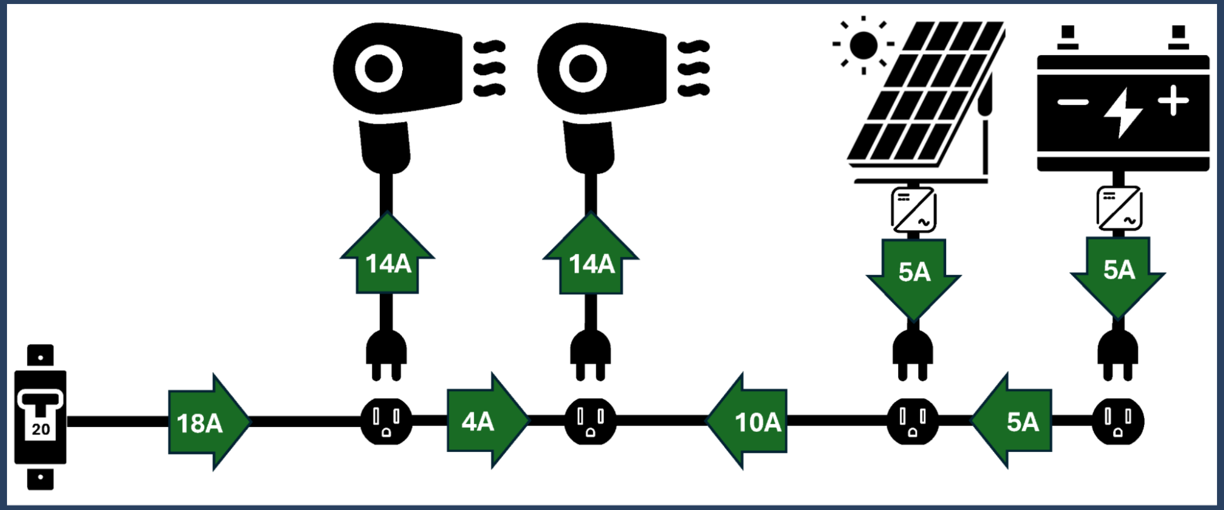
Breaker masking

Another potential fire hazard risk exists: ‘breaker masking’. Even higher currents can theoretically occur without being seen by the breaker, which therefore does not trip. The overcurrent is “masked” from the breaker.

In 2025, a group of experts in the USA published a paper illustrating the issue. In the chart below, the breaker (left) trips when current from the grid passes through it at 20 A. Two appliances (represented on the right by two hairdryers) are consuming 14 A each, would add up to 28 A – more than enough to trip the breaker so that an overcurrent is prevented. However, a solar panel and battery in-between these appliances and the breaker are feeding in 10 A (5 A each), so that only 18 A passes through the breaker from the grid. The breaker does not trip to prevent a section of the circuit reaching a dangerous 28 A.



Note that this configuration requires the PIPV to be situated in-between the breaker and the appliances. Because the PIPV will generally be connected to an outdoor socket, it is more likely to be at the end of the circuit. In such cases, the circuit would not overload, as shown below.



As with insulation around wiring, residents will rarely know if their socket for PIPV is located at the end of the circuit or somewhere in the middle. It is thus best to err on the side of safety. Fortunately, there is a solution: current monitors.

How to monitor and limit current from PIPV

Ideally, the PIPV system would be able to monitor the circuit it is connected to and adjust output accordingly. And that is exactly what is coming next.

Current monitors throttle the microinverter’s output to prevent overheating; Power Control Systems as discussed in UL 3141 for the US also perform a similar function. Current monitors continuously measure all currents flowing into the branch circuit to which the PIPV system is connected. As a failsafe, the PIPV system reverts to the static current limit if communication is interrupted, no updated measurement is received within the required time interval, or the measurement values cannot be

How do I know if my home’s electrical wiring is adequate for a plug-in solar system?

If your fuses regularly trip when you are using large appliances or power tools, you may be using your wiring at its limits. Have it inspected; it may not be suitable for a plug-in solar system. In most homes built in the last 20-30 years, the fuses rarely go off. It is not advisable or legal for laypeople to tamper with the electrical wiring or fuse box in your house due to the high risk of injury. In case of doubt, consult an electrician.

verified. If the PIPV system fails to revert to the static current limit, it disconnects completely.

One drawback of these added components is cost. The energy meter itself does not have to cost more than 100 euros, but an electrician is required for some models to install it to your power meter. The current monitor is DIY equipment but currently costs hundreds simply because these devices are boutique products; once millions of them are produced, the price will plummet. But the cost issue is not a deal-breaker because these devices allow for bigger PIPV systems that will also cost more. A 4 kW PIPV system with 10 kWh of battery storage might cost four thousand euros. An added cost of 400 euros for the energy tracking and current monitoring then might not seem so great. Such system sizes would then allow people to generate most of their own electricity safely from (mostly) DIY products.

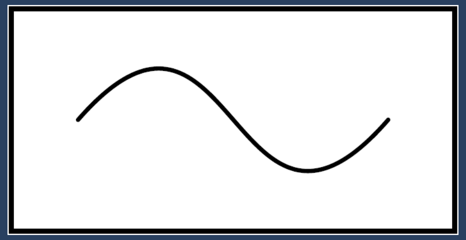
What to do about older wiring, fuses, and breakers?

In older homes, the condition of the electrical supply may raise questions. Can my wiring even handle solar power from PIPV? Are my sockets in good condition? Do I need a new fuse box?

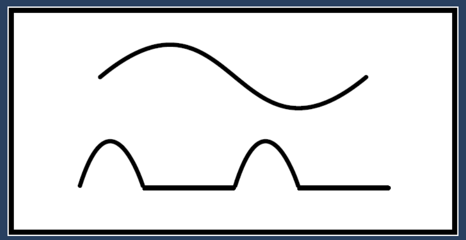
Even though upgrading your home’s power supply might cost thousands, there is no beating around the bush here: If you have any doubt about whether your home is PIPV-ready, have an electrician inspect your wiring and breakers. There is no point risking your house burning down just to save 100 euros annually on electricity.

The following residual current devices (RCDs) are common in Europe; the RCDs are usually labelled, but if they do not use letters, they will display the following symbols below:

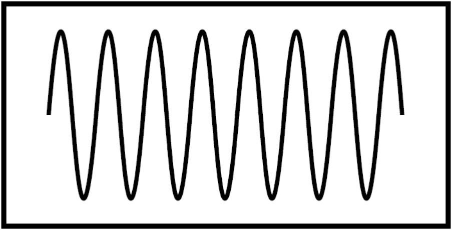
- Type AC: only for alternating currents; rarely recommended today. Not suitable for PIPV due to possible DC leakage.



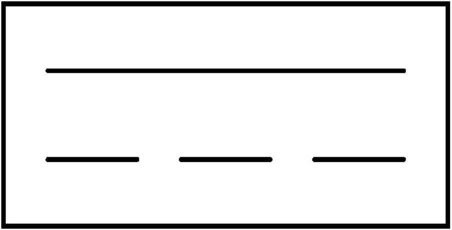
- Type A: standard type for households, detects pulsating direct currents.



- Type F: ideal for modern devices with high switching frequencies, such as heat pumps.



- Type B: used for charging infrastructure, larger solar arrays (rooftops), and industry.



The more modern the electrical devices, the more important it is to choose the appropriate type.

For power sockets, a simple visual inspection suffices. If the one you will plug your PIPV into looks corroded or damaged, err on the side of caution. If your breakers trip more than once a year, the arrangement of your appliances might be taxing a circuit. If you use outdated breakers or even old-fashioned fuses, you should upgrade.

A quick look in your breaker box should reveal whether you need to take action before connecting PIPV. First, make sure you have a breaker, not a fuse. Breakers trip and can be reset; just flip the switch. Fuses blow out and need replacing. They also provide less protection.

Once you have determined that you have a breaker rather than a fuse, look to see which type. This information is usually printed on the breaker. You want to avoid Type AC as they only protect against issues with alternating current. Type A has been more common in recent decades as it also provides protection against DC fault currents (aka DC residual currents).

A building-wide project can ensure a unified look. Photo: Christian Ofenheusle.

PIPV in rentals and shared condos

Although PIPV is often called “balcony solar,” most systems in Germany have been installed on the property of single-family homes, duplexes and townhouses, often on the ground. The latest data are from 2022, but there is no indication that the situation has changed.

The 2022 survey found that 57% of PIPV systems in Germany had been installed in single-family homes. This number is not only a majority, but also higher than the average number of people living in SFH: 40%.

Furthermore, more PIPV systems were installed per capita in the smallest towns with fewer than 5,000 inhabitants.

The data from the German solar registry (Marktstamm-datenregister) up to the end of 2025 show the trend has strengthened: less PIPV is installed per capita as the town gets bigger (see chart to the right).

One other salient finding from the 2022 survey is that most (76%) PIPV systems had been installed by home or apartment owners, not by renters. Germany is an outlier when it comes to renting vs. owning: only 47% of Germans own their homes (including apartments), compared to 60-80% home ownership in most countries.

The main reason why PIPV is still relatively rare in apartment complexes is that home owners can do what they want, whereas condominiums generally require approval from building management (even for apartment owners). Nonetheless, PIPV fills a gap for everyone who cannot make decisions independently about their roofs: tenants and owners of condominiums. So how can this situation be remedied?

German towns with the most PIPV per 1.000 people

Inhabitants	Town	New PIPV units per 1.000 in 2025
More than 500,000	**Bremen**	**3.39**
100,000 - 499,999	**Kassel**	**6.59**
30,000 - 99,999	**Landau in der Pfalz**	**8.55**

Although PIPV is often called “balcony solar,” most systems in Germany have been installed on the property of single-family homes, duplexes and townhouses, often on the ground. Hence, PIPV is found more often in small towns than in large cities, where apartments are more common.

Reasons for PIPV in apartment complexes

Property management can benefit from building-wide PIPV projects. Apartments with PIPV allow residents to save 10-20% on electricity costs. The systems generally pay for themselves in 3-4 years. Tenant satisfaction thus increases.

Generating electricity on-site can also help alleviate the load from the grid, which can free up capacity for EV charging and heat pumps. In Germany, some apartment complexes have installed heat pumps only to discover that their grid connection didn’t supply enough electricity for them to run properly.

In Germany, the million PIPV units in use have not increased safety risks. Hence, insurers simply include PIPV in their standard policies covering household appliances.

Furthermore, the property's image is enhanced because solar panels on facades are more prominent than rooftop solar panels – PIPV becomes an eye-catcher. In addition, balcony solar systems are considerably easier to install and manage than rooftop PV. Finally, they foster a more positive attitude towards renewable energy among residents. PIPV can start a conversation between property management and residents about energy consumption in the building. Most other measures – replacing the heating system, adding insulation, installing better windows, etc. – have much longer payback periods. Starting with the quick payback of PIPV gets the talks off on the right foot as residents benefit quickly. Property management can react proactively or reactively:

Proactive approach

Many landlords – especially in multi-family buildings – want to install PIPV as part of a comprehensive concept. This approach allows them to maintain a uniform appearance for the building. Allowing residents to pick their own panels will result in a mixture of panel sizes and colors (generally black and blue, but some flexible panels have cells on white mats). The result will not be as attractive as a bulk purchase of a single panel type.

Comprehensive projects can also reduce costs through bulk purchases. Property management can then ensure proper installation if an installer briefly inspects all of the units. Furthermore, not all balconies have an outdoor wall socket. Laypeople cannot install sockets; only electricians can.

The only option to an outdoor plug is a flat cable through an existing opening that does not get opened and closed, such as a ventilation slot. Tenants should be discouraged from running flat cables under doors or windows that can be opened and closed as these cables are unlikely to survive for decades.

Having an electrician come by for a single job increases the price per unit – if you can even find an electrician willing to do that small job. In contrast, if the entire building needs sockets on the balconies, the price per unit plummets, and electricians could also be tasked to inspect the installation while they are there doing a larger job.

Building-wide projects, especially those including low-income residents, can often receive public funding. Property management with enough staff resources can not only apply for grants, but also select the systems, organize assembly and installation, and facilitate registration. Companies that lack staff can contract an installer.

Reactive approach

Handling residents' balcony solar projects on a case-by-case basis is not recommended for the reasons given above. But if no building-wide project is possible, property management should develop guidelines and agreements for tenants and staff that minimize the risk for the owners and safeguard the property's value.

There are four main areas to consider:

1) Appearance

While taste is subjective, uniformity and clear structure are generally appreciated. Therefore, establish uniform design guidelines for PIPV. For instance, all-black/full-black modules offer a uniform and high-quality design across various manufacturers and types, combined with maximum efficiency. Coloured solar modules are also available; they may blend better into the facade at the cost of slightly reduced power generation.

2) Mechanical safety

A wide range of mounting solutions for PIPV are available. Few of them have undergone structural analysis. The German product standard for PIPV from December 2025 requires such documentation and also obligates suppliers to provide clear information on suitable installation locations, including mounting height, wind zone, and snow load. As more countries publish PIPV standards, property management will be able to request confirmation from residents that the device complies with this standard and that the mounting solution is suitable for the installation location. Until such time, the liability protection discussed below is sufficient.

PIPV sets are designed to be installed by laypeople. Photo: OneStep.Solar

The load-bearing capacity of the balcony railing is equally important. The relevant load values that railings must generally withstand are defined in the European standard DIN EN 1991-1-1. In addition to the railing's own weight, horizontal and vertical loads are also taken into account. These can arise from people leaning against balustrades, from wind loads, and potentially from other loads such as flower boxes, satellite dishes, parasols, and solar panels. The issue is less severe with masonry and concrete railings, which can withstand significantly higher loads; however, installation on these materials usually involves drilling. (In this case, the installation leaves its mark on the building after the PIPV system is taken down.) Here, a specialist company should be contracted as the building structure is affected, and installation – especially on upper floors – cannot be safely carried out by laypeople. The same applies to any installation on the facade.

The situation is different for railings made of steel, wood, or other materials. For these, the horizontal load at the height of the railing post is relevant for calculating the load-bearing capacity. In residential and office buildings, a general minimum value of 0.5 kilonewtons per meter applies, which corresponds to approximately 50 kg per meter of railing. If this is not guaranteed, it is the building owner's responsibility to remedy the situation even without PIPV. Generally, privacy screens made of plastic and mounted vertically can generate comparable wind loads to a framed, elevated plastic solar module. If the former is permissible, the latter can hardly be rejected. Furthermore, the weight of the module and the mounting structure must be considered: between 2 and 25 kg per module. It is the landlord's responsibility to clearly state the load-bearing capacity of the railings and, on this basis, provide residents with clear guidelines on module types and their installation.

Escape routes must also be kept clear. Fire departments usually insist on unobstructed parapet areas with a width of 1.20 meters. This area must be available if PIPV obstructs easy access to the balcony.

3) Electrical safety

Balcony power plants generate electricity. Therefore, they must be treated differently than ordinary household appliances in some respects. A standard household connector for a hairdryer or toaster can be used if the entire electrical installation meets basic standards. If the property has outdated, dilapidated, or otherwise damaged wiring, fuses, or other components, then – as with the balcony railing – the owner is responsible for rectifying these issues, regardless of whether a plug-in PV module is used. If there is any doubt, the owner is obligated to have an inspection (such as an electrical safety check) carried out by a qualified electrician. Thus, PIPV can be the occasion for a more general electrical upgrade for the building.

PIPV systems can be installed on shared rooftops to increase solar output and connected separately to each apartment's power meter: Photo: Georg Löser.

The same applies to upgrading the central power meter box. Old meters are gradually being replaced by digital ones anyway. PIPV simply pulls this process forward. These expenses can be included in general operating costs.

4) Liability for damages

In principle, users are liable for any damage to the building, property, or third parties caused by a PIPV system – however unlikely it may be. In Germany, the million PIPV units in use have not increased safety risks. Hence, insurers simply include PIPV in their standard policies covering household appliances.

Nevertheless, it is understandable that property owners want to protect themselves. In the event of damage, the building insurance company is the first point of contact. Some money can often be recovered from the tenant's liability insurance. Therefore, it should be clarified with the building insurance company whether proof of liability insurance from the tenant should be provided.

Waiting until the issue becomes impossible to ignore will create more work than addressing it early on. We therefore recommend that landlords consider how they want to handle balcony power plants as soon as possible.

A woman enjoys her new solar balcony in Poland. Photo: OneStep.Solar.

A template for PIPV guidelines for property management

Management generally consents to the use of plug-in solar devices on the property. For the safety of the tenants and the integrity and appearance of the building, the following principles should be observed.

Device type

To ensure personal safety, only devices that comply with applicable legal and regulatory requirements may be used. In particular, a certificate for grid protection according to VDE-AR-N-4105 and compliance with the product standard VDE-V-0126-95 must be obtained.

Only devices whose components have been assembled by a specialist retailer may be used in order to prevent overloads and other potentially dangerous malfunctions.

To maintain a uniform facade appearance, solar modules with the same visual design, such as "full-black" modules, should be used on all balconies and other facade surfaces.

Installation

When installing on the balcony railing, care must be taken to ensure that any necessary work on masonry and other facade elements (such as drilling) does not impair the integrity of the building structure or its appearance, even after dismantling.

It must be ensured that dismantling can be carried out without leaving any mark. The original condition of the rental property must be restored at the tenant's own expense upon moving out.

Modules may only be mounted on the balcony railing or facade at an angle of no more than 25° to the vertical to minimize wind and snow loads.

Should temporary or permanent removal of the plug-in solar device be necessary due to repair, maintenance, modernization, or expansion work, no claims for damages or other compensation can be derived from this.

Connections

A plug-in solar device must never be operated using a power strip. A connection can be made via a wall socket (a grounded socket is sufficient) or a permanent connection installed by a qualified electrician.

If there is no outdoor wall socket, property management should provide information on possible alternative connection options, such as a window feed-through, connection to a lighting circuit, etc., or provide information on other ways to enable a connection, such as the installation of a new wall socket by management or a specialist company commissioned by the resident at their own expense.

Any additional costs incurred for meter replacement by the grid operator are to be borne by the connection holder (property management).

The tenant must register and unregister the plug-in solar device. Any transfer of these responsibilities to the landlord must be agreed separately.

Liability

The resident is fully liable for any damage caused by or to the plug-in solar device. Property management may request proof of the tenant's liability insurance. By signing below, we acknowledge these terms and conditions.

______________________	______________________
Property management	Resident

Calculating payback

How quickly will my PIPV system pay for itself? This simple question is the main one buyers will ask – and yet, it is not so easy to answer. In Germany, payback can be expected in around 3-4 years under good conditions. For a system with warranties lasting much longer, the investment will pay for itself many times over.

Typical warranties for PIPV components:

- Solar panel: 20-25 years of product warranty, 25 years of performance warranty (80% of initial output)
- Inverter: 10 years
- Mounting system: 10 years
- Battery: 10 years

The payback is calculated based on two factors: how much electricity is produced and what is its value. Both factors can differ significantly from one household to another, not just from one country to another.

As we move towards the equator, panels mounted vertically on balconies facing the equator gradually become the least efficient option. A slope helps (the panel is standing at a 70° angle instead of 90°), as does an orientation facing east or west.

Estimating power generation

The EU's Photovoltaic Geographical Information System (PVGIS) is a good starting point to calculate how much electricity a PIPV system can generate across the world. To make comparisons simple, we assume the system has an 800 watt inverter and 1,000 watts of panels. In all of the examples below, we will also assume no shading; shading can cripple an array's output. Avoid installing PV in the shade if possible.

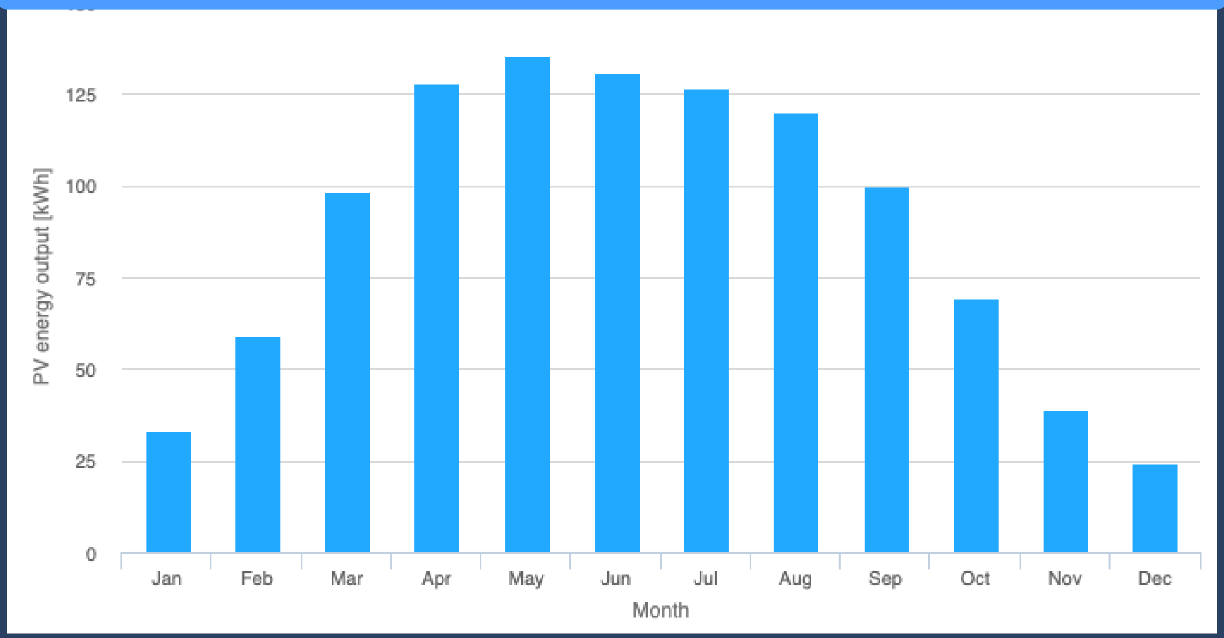
A slope between 20° and 40° from the vertical 90° yields up to 30% more on average per year than a vertical mounting.

The first system we will look at is located in Berlin at a latitude of 52.5° N facing due south. For comparison, the US-Canadian border is around 49° N, whereas Australia lies fully between 10°S and 40°S, while 30°S roughly cuts South Africa in half. The optimal slope will usually only be possible on roofs or on the ground.

Effect of various PIPV orientations relative to an ideal orientation in Berlin, Germany (52.5° N).

Installation type at 52°N	kWh/a	Reduction
Optimal slope (35°)	1064	(baseline)
Vertical (90° slope)	773	27%
Slanted (70° slope)	996	9%
East, 90° slope°	541	49%
West, 90° slope°	490	54%

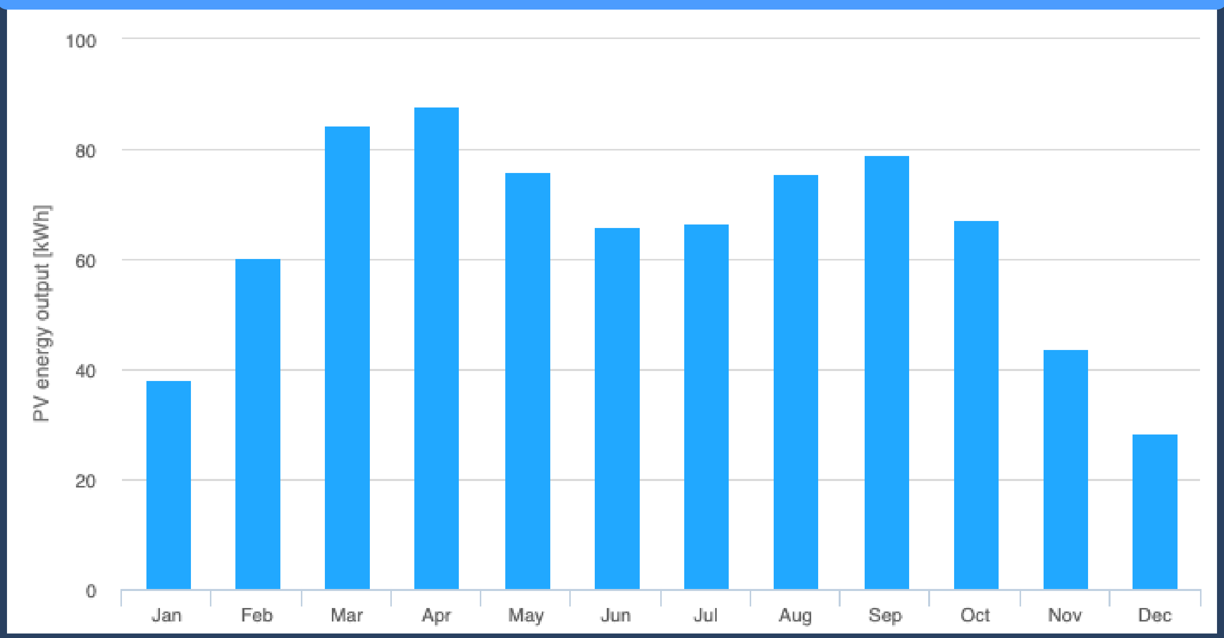
Power generation from a solar array with an optimal orientation (35°) in Berlin, Germany.



A panel mounting vertically on a balcony in Berlin would thus produce a good quarter less electricity over the year than one installed at the optimal slope for Berlin (35°). When this loss happens is interesting: The curve for PV production is usually high in the summer and tapers off towards the winter, as shown above for the 35° slope in Berlin.

But at a 90° slope, the panels begin to lose efficiency as the sun rises on the horizon; vertical panels are simply at too acute an angle relative to the sun high in the sky. The result is a valley in the summer surrounded by two peaks in April and September, as shown on the next page.

Power generation from a panels on a balcony (90° slope) in Berlin, Germany.



Durban, South Africa, is located at 30°S, which runs just south of Brisbane, Australia, and is equivalent to 30°N running through New Orleans, USA, and close to Cairo, Egypt. At this latitude, PVGIS has the optimal slope at 30

Effect of various PIPV orientations relative to an ideal orientation in Durban, South Africa (30° S).

Installation type at 52°N	kWh/a	Reduction
Optimal slope (35°)	**1529**	**(baseline)**
Vertical (90° slope)	915	**40%**
Slanted (70° slope)	1257	**20%**
East, 90° slope°	704	**54%**
West, 90° slope°	694	**55%**

Here, we see that power production is roughly cut in half for balcony solar as opposed to ground-mounted or rooftop. However, something interesting happens when we change the azimuth so that the panels are facing 90° east or west. Now, power losses are closer to 40°. But the main difference will be the time of day: west-facing panels will not begin generating electricity until after noon, and output will remain strong into the early evening – and vice versa for east-facing panels. South-facing panels can expect to generate most of their electricity between 9 am and 3 pm.

These differences in the time of day will become important when we discuss on-site consumption. But first, let's take a look at 10°N in Ho-Chi Min City, Vietnam, with an optimal slope of 10°.

Effect of various PIPV orientations relative to an ideal orientation in Ho-Chi Min City, Vietnam (10° N).

Installation type at 52°N	kWh/a	Reduction
Optimal slope (35°)	1408	(baseline)
Vertical (90° slope)	576	59%
Slanted (70° slope)	908	35%
East, 90° slope°	737	47%
West, 90° slope°	608	57%

Here, the power generated is much greater for 90° vertical installation if the panels are facing east and slightly better if they face west than south. One conclusion is then obvious: **As we move towards the equator, south-facing panels mounted vertically on balconies gradually become the least efficient option**. Near the equator, an orientation facing east or west performs better than an orientation facing the equator – the sun then hits the panel at too acute an angle.

A second conclusion is that **a slight slope provides a considerable performance boost** in all of the examples above.

Now that we have estimates of annual solar power generation, we see that output can vary significantly, making ROI calculations difficult. And it gets worse: in many countries, there is little to no compensation for electricity exported to the grid. In other words, PIPV systems pay for themselves most quickly when someone is at home during the day to consume power immediately. Some appliances – washing machines, dryers, and dishwashers come to mind – can be set to run during the day, but people still want to cook supper in the evening.

Home energy management systems help tailor power consumption to solar power generation, and batteries make a huge difference. But batteries can also double or triple the cost of a PIPV system. In the spring of 2026, PIPV systems with 1,000 watts of panels were on sale for 400 euros in Germany, but adding a 2 kWh battery brought the price up to 1,000 euros. Battery prices continue to fall, so storage will increasingly pay for itself, but let's take a look at an ROI calculation for PIPV without storage to get started. To do that, we need to overlay household consumption over solar power production.

A table of payback in six countries

Solar electricity that is consumed immediately offsets the retail rate. The problem is that, without a battery, this consumption must take place immediately.

In general, around a third of PIPV power generation can be consumed directly without further optimizing consumption patterns. By moving more power consumption into the hours of power generation – remote work and timing appliances like washing machines – that share can be doubled. If the household consumes a lot of power (large households, air-conditioning, etc.), the share of solar power consumed on-site will tend to be higher.

In all of the countries except Vietnam, PIPV pays for itself in around eight years or fewer under conservative assumptions. In four of them, the payback is between 4-6 years. The main factor is the retail power price being offset.

To make the estimate simple, we will assume 50% on-site consumption except for the United States and Australia, where household power consumption is greater and air-conditioning is common, and Ho-Chi Min City in Vietnam, where air-conditioning is becoming widespread – 90% direct consumption is assumed these three cases. Two panels with 1,000 W are assumed to face the equator at a 90° slope except for Vietnam, where a 70° slope is assumed.

Country	Power gen in kWh/a	On-site consumption rate	On-site consumption (kWh)	Retail rate in euros	Savings/a	Sales to grid	System cost €	Payback in years
Germany (Berlin)	618	50%	309	0.38	117 €	0%	500 €	4.26
Poland (Warsaw)	621	67%	416	0.26	108 €	8%	680 €	5.82
USA (Kansas City)	796	90%	716	0.14	100 €	0%	500 €	4.99
Australia (Brisbane)	692	90%	346	0.18	112 €	0%	500 €	4.46
Vietnam (Ho Chi Min City)	726	90%	654	0.08	52 €	0%	500 €	9.56
Ireland (fields of Athenry)	560	50%	280	0.33	92 €	17%	500 €	4.63

How batteries change payback

Plug-in batteries pay for themselves faster when levels of own consumption and compensation for power exported to the grid are low. Own consumption increases when the PV system is smaller and household consumption is greater.

A 2 kWh battery (the entry-level plug-in battery) can allow a PIPV system to reach 90% own consumption. However, the battery can double or triple the cost of a PIPV system. In the spring of 2026, the 1,000 W reference system used in this paper could be bought for 500 euros in Germany. Adding a roughly 2 kWh battery brought the cost up to at least 1,000 euros.

To make the calculation more complicated, batteries have warranties not exceeding 10 years. If they take a decade to pay for themselves, it's a wash.

The full battery capacity is not available either. Deep discharge below 20% is not recommended, and batteries also like to stay below 80%. Effectively, 60% of the battery's capacity is available for regular ramping, so a 2 kWh battery offers 1.2 kWh effectively.

That amount is nearly enough to cover the 1.5 kWh that a one-person household consumes in many European countries. But as the household consumption grows, the home will be able to consume more solar power directly, leaving less work for the battery to do.

The three factors for the payback of plug-in batteries are:

- their price;
- the increase in own consumption they provide (households with very high levels of own consumption benefit less from batteries); and
- price signals for arbitrage.

Arbitrage means that the battery charges when grid prices are low and discharges when they are high. Here, own consumption does not always matter. The price signals apply regardless of solar power generation from PIPV.

Obviously, batteries offer other benefits. Indeed, they are selling like hotcakes in most countries even where they don't have proper price signals for arbitrage. Although heavy, they are portable and can provide significant amounts of electricity for garden parties, camping etc. They can also serve as emergency power sources during blackouts.

Plug-in batteries increasingly sell for less than 500 euros per kWh in mature markets.

In January 2026, German NGO Balkonsolar compared four scenarios for the payback of PIPV. The results are specific to the country, but the overall trend should apply everywhere.

Household consumption in kWh	Panel size in W	Storage size in kWh	Payback in years
1500	450	0	5
1500	450	2	13
2100	960	0	6
2100	960	2	13
2100	1600	0	6
2100	1600	2	8
4000	1600	0	4
4000	1600	2	8

Here, PIPV without storage pays for itself in every case within 4-8 years. Given performance warranties of 25 years, PIPV can be expected to pay for itself several times over. The situation is different for the 10-year warranties of batteries. In the two smallest cases of household consumption and panel size, the batteries do not pay for themselves within their warranty period. Only when the panel size and household consumption are bigger, do the batteries pay for themselves – and that just barely.

This calculator is based only on self-consumption. Another way of financing batteries – one that also serves the needs of the grid – is dynamic pricing that reflects the needs of the grid. Germany does not have this option for small batteries at present. Numerous countries have time-of-day pricing, which roughly reflects aggregate grid situations, but truly dynamic grid prices would be offered every 15 minutes or even faster (intervals of one second are already possible) and reflect local conditions on the distribution grid.

The fluctuating grid prices that Germany offers to larger batteries provide price swings of up to 20 cents per kWh. Plug-in batteries would indeed pay for themselves well within ten years if they could leverage these price swings on a daily basis. The batteries would then also help support the grid, thereby reducing the need for expensive grid expansion.

Plug-in storage without solar

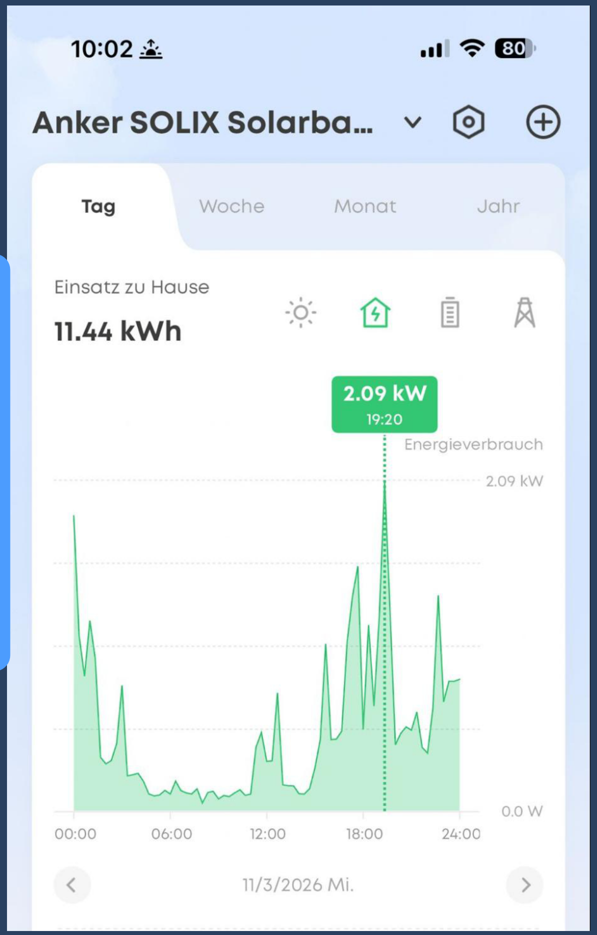
One emerging sector is being woefully overlooked: plug-in storage without solar. The number of households that can have PIPV is limited: Not every home has a balcony or yard facing the right direction without shading. But practically every home has the space for a battery the size of a carry-on bag in the corner or under a table.

According to a survey in 2025, 26% of German households already have or can imagine getting PIPV. If nearly 100% of households would be suitable for plug-in storage, it is imaginable that 50% of households will want it.

A 5 kWh plug-in battery for 1,000 euros would pay for itself through dynamic pricing. Germany currently has 41 million households. If 20 million of them had 5 kWh of power storage capacity, the total would be 100 GWh of capacity. Estimates for mid-century put Germany's battery storage requirements at up to 500-600 GWh; lower estimates come in around 180 GWh.

In either case, plug-in storage could provide much of the flexibility Germany needs, and it would not require any subsidies; grid-supporting dynamic pricing would suffice. The situation is similar in other countries. All policymakers need to do is provide plug-in storage with dynamic pricing that reflects grid needs.

The batteries used with PIPV are almost always LFP (lithium-iron-phosphate), which are inherently safer than the lithium-ion batteries in laptops and smartphones. LFP batteries also have several times more charge cycles, so they last much longer.



Plug-in batteries increasingly come with apps that allow users to monitor their solar power generation and consumption. Photo: Anker SOLIX.

Home energy management systems (HEMS)

Above, we discussed energy trackers, which are attached to power meters. They help households reduce consumption from the grid by increasing direct consumption of solar power, largely via batteries. But energy trackers don't affect the way appliances operate – that's the job of HEMS (aka smart homes, smart appliances, etc.).

A WiFi connection between the apartment and the power meter, which could be several stories away in the basement, might not be possible. But other configurations are available, and we can expect manufacturers of batteries and HEMS to start developing end-to-end systems: PIPV with batteries, energy tracking, and circuit protecting current monitors.

People will perceive higher power prices as an inconvenience for many appliances, such as cooking dinner. But some power-hungry chores, such as washing clothes and dishes can be timed without much inconvenience. Thermal applications – think heat pumps and refrigerators – can also store electricity as cooling or heat; they run when power prices are low and switch off when prices rise. Electric vehicles can also be charged via HEMS.

In 2025, German researchers provided the following overview of HEMS functions pertained to batteries:

Hardware:

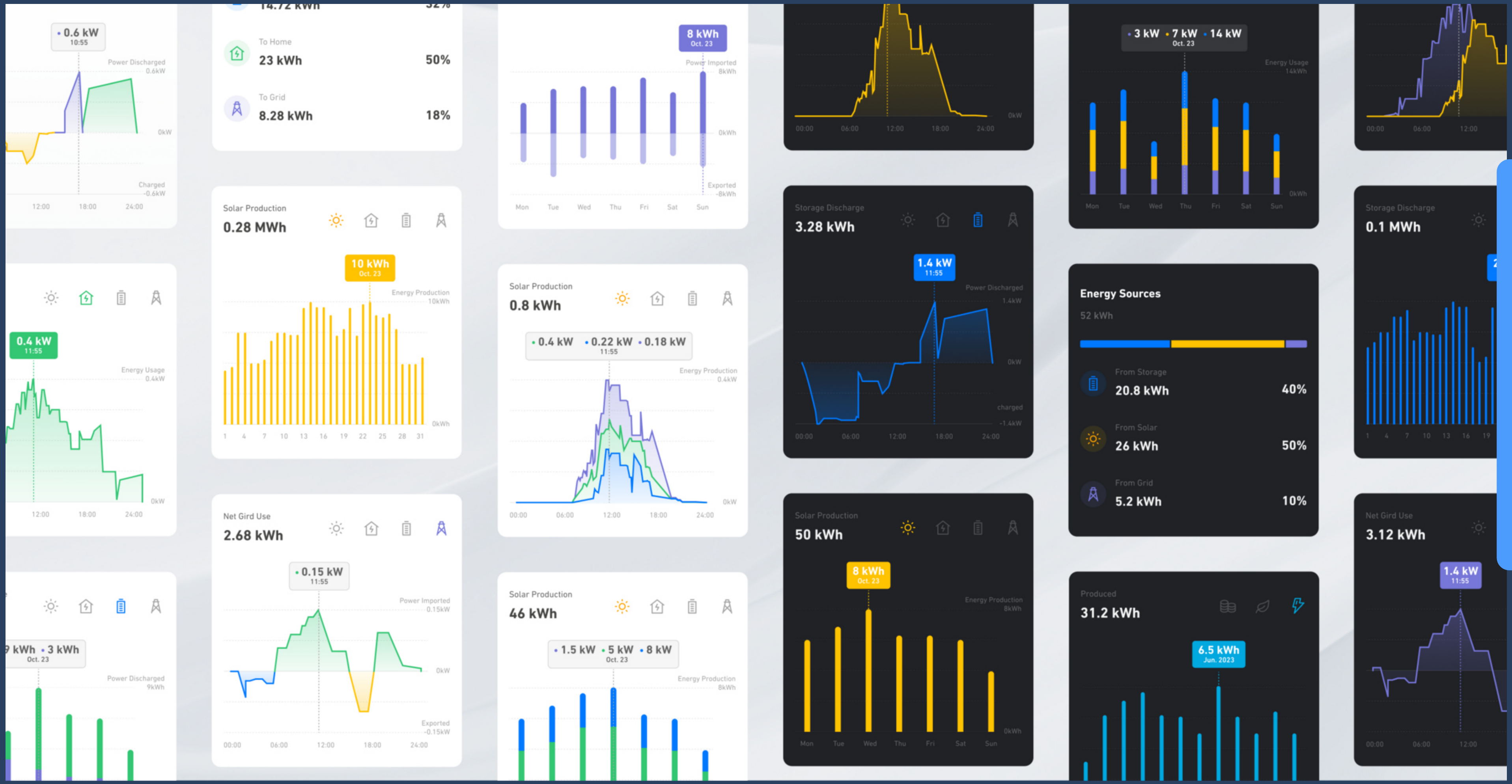
- ♦ Charge and discharge planning based on local hardware or cloud server
- ♦ HEMS integrated in inverter or battery

Software:

- ♦ Forecasts for charging and discharging
- ♦ Individual configuration of forecast-based charging and discharging
- ♦ Forecasts on by default
- ♦ Forecast-based charging and discharging without backfeed limit
- ♦ Forecast-based charging and discharging without constant internet connection
- ♦ Forecast timeframe for charge planning (17-72 hours)
- ♦ Intervals between next update for charge planning (10 minutes was the shortest)
- ♦ Forecasts
- ♦ Consumption and production forecasts can be based on historic data
- ♦ Inclusion of local online weather forecasts

Additional functions:

- ♦ Brief charging from excess solar power in the morning
- ♦ Stepless throttling of the solar panels
- ♦ Battery-friendly charging (avoiding max levels)



Modern Home Energy Management apps provide a wide range of information about a household's energy generation and consumption – and allow users to optimize solar energy consumption. Photo: Anker SOLIX.

PIPV in developing countries: the case of Papua New Guinea (PNG)

Most of the countries discussed in this white paper are in the Global North. The situation for PIPV in the Global South can look fundamentally different, though details still vary from one country to another. For one, households may lack the money needed to purchase PIPV – some kind of financing is needed. Fortunately, small solar power systems (Solar Home Systems) are already widespread in many parts of the Global South, and the technology used in PIPV is essentially the same. They are commonly financed through pay-as-you-go (PAYGO) schemes. Essentially, a funder provides the solar sets for free, and users pay for the electricity as it is consumed, sometimes in advance. PAYGO can also be used for PIPV.

In low-income countries, electricity prices are often subsidized so that more households can afford a base level of electricity. Lower power prices means PIPV takes longer to pay itself back – but deflated prices cause other social and financial issues as well.

To take one example, Papua New Guinea’s power utility, PNG Power Ltd (PPL), is technically insolvent primarily because of fixed electricity prices lower than the cost of production. Despite these artificially deflated prices, illegal connections are common enough to be politically and operationally significant. Would the utility benefit from plug-in solar and battery kits combined with a smart meter rollout?

The case for PPL is mostly cost savings: fuel burned, network wear, safety risk to field crews during disconnection exercises, and ongoing billing and enforcement. Shifting the illegal load off-grid with PIPV would not meaningfully erode PPL's revenue base; it was never being paid for this electricity in the first place. PIPV would, however, reduce operational drag and free constrained generation and network capacity to serve sales to C&I and paying residential customers – where the margin actually sits and where reliability matters most for PNG's wider economy. The case is strongest in settlements adjacent to existing grids, rather than in fully off-grid rural areas already served by small solar home systems.

Two caveats remain. First, PPL currently lacks the feeder-level loss data needed to confirm where settlement losses are heaviest, so any rollout sequencing depends on building that visibility. Second, the underlying affordability constraint remains: settlement households cannot front-load the capex, so donor-funded hardware, PAYGO repayment, and backing from the National Energy Authority are prerequisites for the package to actually land.

What about public acceptance? To work effectively, any scheme needs to be genuinely attractive to settlement households on their own terms: reliable power, better electricity services, and cheaper electricity than the status quo. The status quo for most settlement households is already a cheap imported solar kit handling lighting and phone charging, topped up with kiosk charging and the occasional shared generator. So the value proposition has to be an upgrade: running a fridge, fan, TV, maybe a rice cooker. Modern PIPV sets can easily power these appliances, but the upfront cost remains prohibitive for low-income households. Affordability thus has to be engineered in from the start: some combination of donor-funded hardware, PAYGO repayment structures, and an NEA-approved lifeline tariff block that includes grid support from batteries. Without that affordability architecture, even a well-designed technical package won't get traction.

Resilience: PIPV as backup power

PIPV can provide backup power, but its potential should not be overstated. The inverter must be able to operate in offgrid mode – not every one can.

As explained above, inverters have an anti-islanding feature designed to prevent them from outputting any electricity as soon as the connection to the grid is lost. This feature prevents solar arrays from injecting electricity into the grid during an outage, when technicians might be repairing power lines. This feature is important as it could save lives.

However, some inverters can be switched into offgrid mode. They can then continue generating power to charge a battery – not input power directly into the household circuit. The battery's power socket then becomes the only outlet in the home.

A 1,000 W system can be expected to generate 500 Wh of electricity in a day on average. This is not a lot: even a one-person household in Germany would consume three times that much. However, a little is much better than nothing, and a 2 kWh battery may only have 1 kWh stored in it when the power goes off.

The battery would be left connected to the panels for the six hours when they produce the most energy. The battery could then be taken into the home to run, say, lamps and a refrigerator. The refrigerator can be especially important not only for food, but also medical supplies. The next day, rinse and repeat.

PIPV would still only be part of an emergency plan, which would include at least:

- ♦ a hand crank radio, which usually also has a flashlight and small solar cells to power it during the day;
- ♦ canned food and bottled water supplies (two liters a day per person;
- ♦ cash;
- ♦ candles and lighters; and
- ♦ a camping cooker.

The camping cookers are crucial as cooking is power-hungry. You want to shift as much energy demand away from electricity during a power outage. Security experts often recommend stocking enough supplies to cover one to two weeks.

A brief history of PIPV

In 1994, Dutch electrical engineer Henk Oldenkamp presented the first micro-inverter at the IEEE's first World Conference on Photovoltaic Energy Conversion. The technology become widespread in solar arrays in which a string inverter serving many solar panels would have suffered great losses from shading. By converting solar DC into AC, the microinverter ensured that a shaded panel or cell would not limit the entire string's production. These microinverters were thus not originally intended to plug solar panels into household circuits.

But there was immediate "technology creep": the microinverters started to be used for unintended purposes. In the mid-90s, the International Finance Corporation (IFC) and the World Bank used the technology to provide people without grid access in poor countries with a modicum of electricity. Within the first decade, nearly 700 million USD had been invested in 1.3 million systems, which usually consisted of a panel, a micro-inverter, a lead battery, and an appliance or two (often a lamp and a radio).

In 2001, German engineer Holger Laudeley began charging his electric vehicle from a plug-in solar unit and started propagating the device as "balcony solar." These systems remained relatively rare in developed countries until the mid to late 2010s, when PIPV began to reach "grid parity" – the point where the cost of the solar power was lower than the retail power rate. At that point, developments progressed in four stages in Germany:

1. Up to 2017, PIPV was in the "guerrilla PV" phase, with no clear regulations.

2. From 2017-2022, PIPV's technical acceptance increased. German engineering group VDE clarified how PIPV could be connected. A 600 W limit was set for inverters. And distribution grid operators offered simplified registration.
3. From 2023-2024, policies accelerated in the wake of the energy crisis after Russia invaded Ukraine and Germany started weaning itself off of Russian gas. Simplified registration became national law. No approval was needed from the power supplier. The 600 W limit for inverters was raised to 800 W. VAT was lowered to 0%. And citizens got a "right to install".
4. In 2025, Germany published the world's first PIPV standard covering electrical and installation issues.

The guerilla phase was global and may have started in the US, where a Guerrilla Solar Manifesto was published in the 1990s in Home Power magazine. Spanish NGO Fundación Tierra conducted an international Guerilla Solar campaign, for which they received the Eurosolar Prize in 2009.

In the second phase, a group of German civil-society campaigners behind the platform MachDeinenStrom.de ("Make your own power", now the BVSS's official newsletter) played a crucial role in getting technical acceptance for PIPV. They called some 600 of Germany's 866 distribution grid operators to convince them to allow for a simplified registration process; up to then, PIPV needed to be entered in a form made for electricians, not laypeople. Getting these simplified forms was essential in moving PIPV out of its guerilla phase as laypeople were simply not registering their systems.

What are standards?

Standards have been around for a long time. Written three thousand years ago, the 3rd Book of Leviticus in the bible includes: “Do not use dishonest standards when measuring length, weight or quantity. Use honest scales and honest weights.”

In the industrial era, standards moved beyond ethics and became instruments of promoting safety. In 1901, the UK founded the first national standardization institute: the Engineering Standards Committee (now the British Standards Institution).

In 1904, the Great Baltimore Fire was only so big in the USA because fire fighters from other cities who came to help could not connect to local hydrants. The result was a national standard for fire hydrant and hose connections. Not every city complies with the standard, however, which is why the Oakland, California, firestorm of 1991 was so large.

More recently, standards have become tools to promote trade. And here, we see why non-compliance is possible: Not all standards are mandatory. According to WTO rules, “standards are defined as voluntary and technical regulations as mandatory.” The main concern here is, say, that one country might adopt standards in order to protect domestic manufacturers from foreign competitors.

For PIPV, the distinction between voluntary standards and mandatory regulations is crucial. Standards that require, in all cases, work only an electrician can perform (especially dedicated circuits and special sockets) will lead laypeople to consider these standards voluntary as long as the equipment is legally on sale. The result of stricter PIPV standards would then be safer compliant systems, but more numerous non-compliant ones.

Some 700 years ago, the size of bread loaves were carved into the facade of Freiburg’s cathedral; people who bought bread at the farmer’s market at the cathedral could hold their purchases up to the wall and see if they had been treated fairly. The years are carved in Roman numerals next to the shapes for bread sizes. Photo: Lutz007, CC SA 2.5.

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Wind zone maps

EU wind zones and global wind speeds are available from Dlubal here:https://tinyurl.com/3vcyjwbw

For Australia, see:

https://www.auspangroup.com.au/wind-regions-australia/

https://www.domeshelter.com.au/wind-regions-map/

For the United States, see:

https://basc.pnnl.gov/images/wind-zones-us

https://windatlas.ca/maps-en.php

Q: What does electricity from PIPV cost in 2026?
A: How does four cents sound?

In the following calculation based on German conditions, we will assume that a 1,000 W system costs 500 euros. In Germany, 1,000 watts of PV can be expected to produce around 1,000 kWh annually under ideal conditions. (Note that countries with better sunlight conditions can easily expect 50% more – so adjust accordingly.) However, a vertical panel on a balcony is not ideally oriented. We will therefore deduct 30%, giving us 700 kWh annually.

Solar panels usually have a performance warranty of 25 years these days. They are thus expected to produce 80% of their rated output at the end of that service life.

If we calculate 90% as an average, we get:

700 kWh * 90% * 25 years = 15,750 kWh

Premium microinverters can also have a warranty of 25 years, though 15 years is not uncommon. Replacing the microinverter once adds around 100 euros to the system cost. If we then divide the (500 + 100 = 600) euros by the 15,750 kWh generated, we get 0.038 euros – just under four cents.

The performance warranty of a battery is usually 10 years. One 2 kWh battery can easily double the price of a 1,000 watt system, but even then the cost of the electricity is only 7.6 cents. When the battery is replaced after ten years at a cost of 500 euros, the price of a kWh in the second decade is then 11.4 cents.

In countries closer to the tropics than Germany is, the kWh price would be cut by a third, putting a kWh around 2.7 cents – or 5.4 cents with storage in the first decade and 8.1 cents in the second.

The main reason for this low price is that people can install the equipment themselves – no roofer or electrician is needed.

Of course, many users will calculate payback based on the savings relative to the retail power rate. See inside.

German Plug-in Solar Association
Bundesverband Steckersolar e.V.
Hans-Fallada-Str. 3
12683 Berlin

+49 (0)30 98557087
info@bundesverband-Steckersolar.de

Visit us at:
Hermann-Blankenstein-Straße 28
10249 Berlin