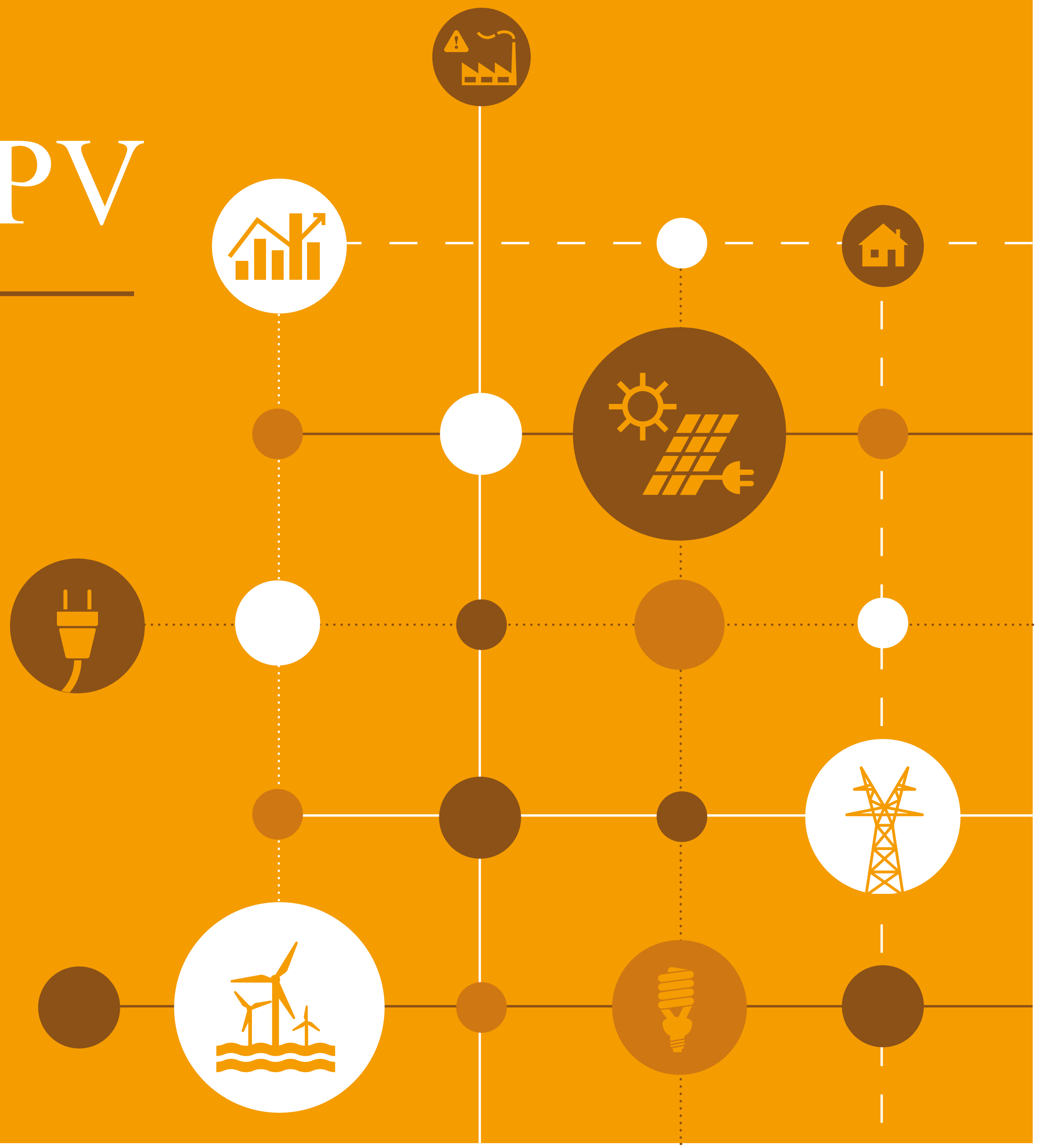
Five minute guide

Rooftop Solar PV

ARUP



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What is a rooftop PV system?

A solar photovoltaic (PV) system, mounted on the roof or integrated into the façade of a building, is an electrical installation that converts solar energy into electricity. This can be used to meet the building's own energy consumption requirements or, in certain situations, fed back into the electrical grid.

Rooftop solar PV systems are distributed electricity generation options, which help to meet a building's energy needs, or provide electricity within an existing distribution network.

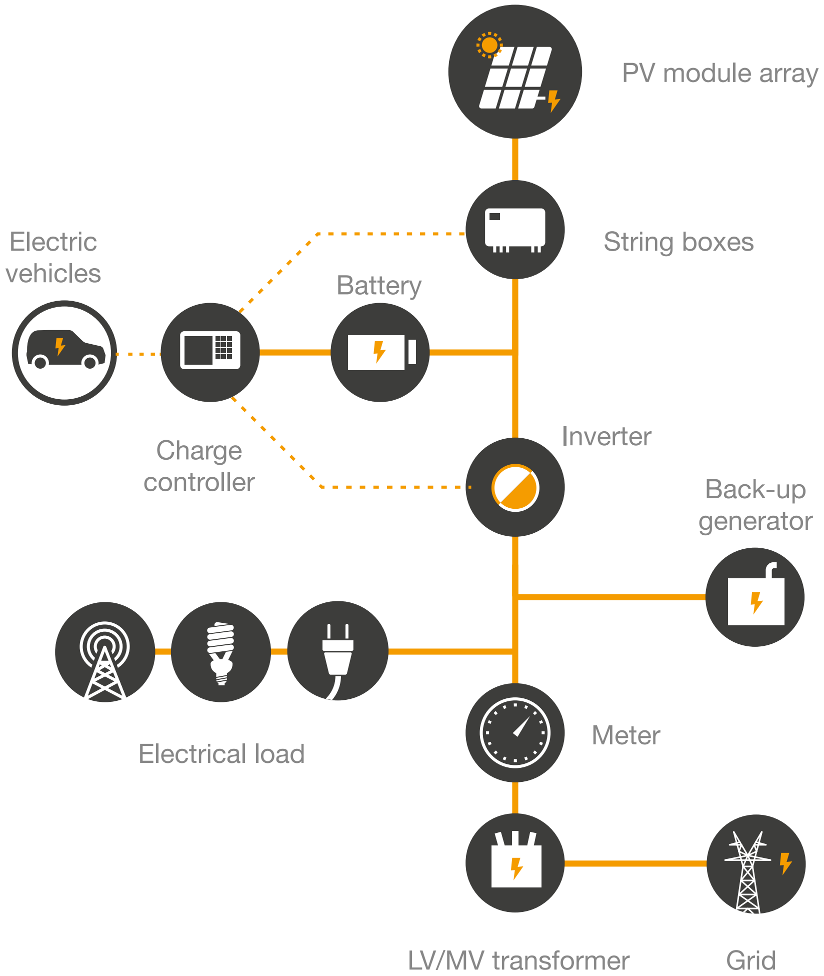
The size of the installation can vary dramatically, and is dependent on the size of the building, the amount of electricity required, the funding available for the project, and the grid operator's willingness to accept excess capacity.

Core system components include PV modules, their accompanying mounting structure and an inverter.

However, other components can also be incorporated into the system, depending on its size and complexity. These include:

- string boxes;
- batteries;
- generators;
- transformers; and
- meters

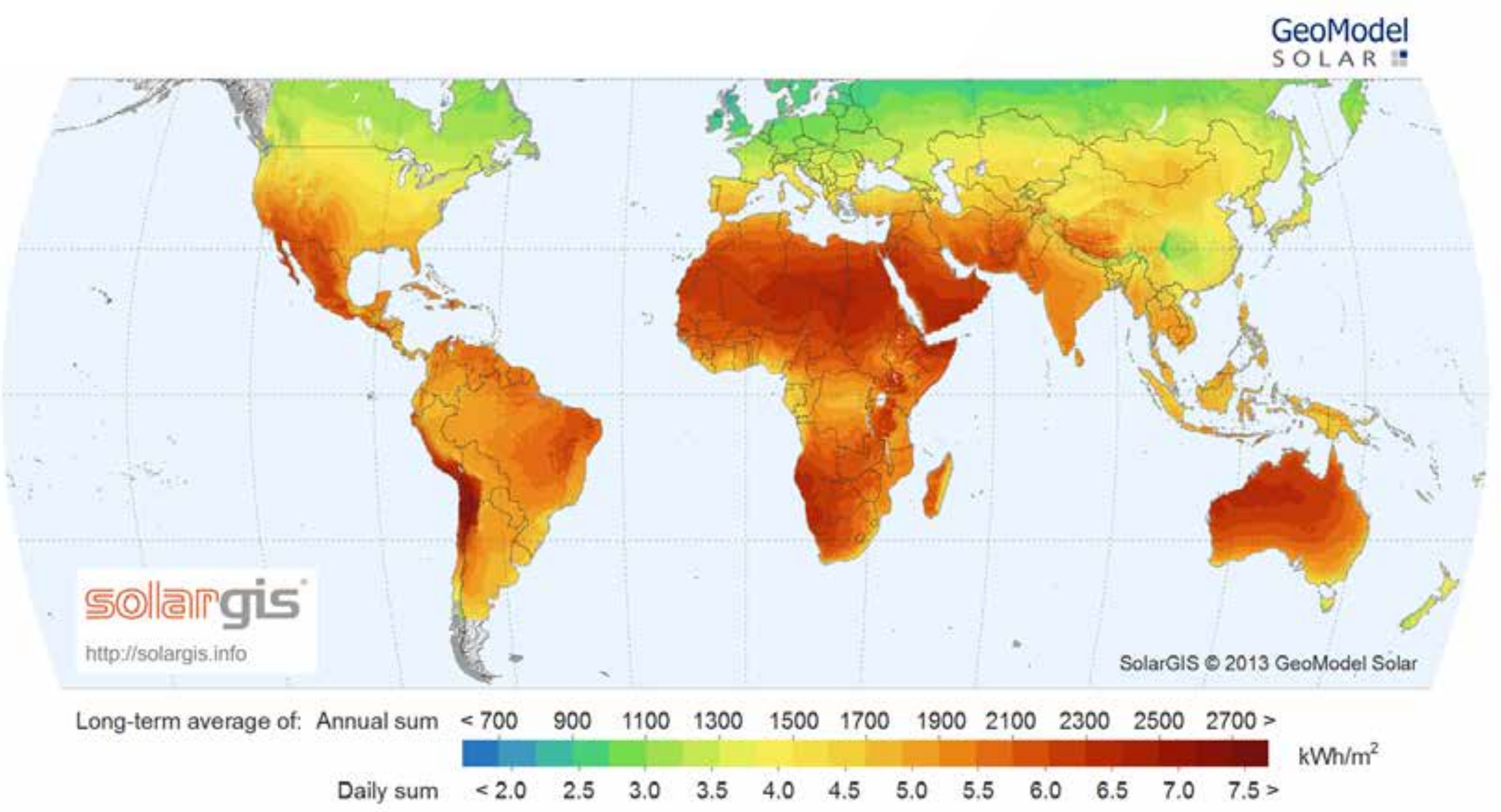
The layout and configuration of systems can differ, depending on the load type and the energy supply requirements. An indicative layout is shown to the right.



Global solar resources

Global solar irradiation has the potential to meet all of our energy requirements and recent installation growth rates in the PV sector have demonstrated the potential for benefitting from this abundant resource, even in areas with lower than average irradiation.

World map of global horizontal irradiation



Installation growth trends

Recent years have seen a rapid increase in the installed capacity of PV systems around the world.

The number and size of PV installations has increased exponentially since 2000, with Europe, China, the Americas and Asia-Pacific driving this growth.

The increase in the uptake of solar PV installations is influenced by:

- decreasing PV technology costs;
- economies of scale achieved;
- the learning curve associated with utility scale installations;
- increasing grid supplied electricity prices;
- the availability of preferential feed-in-tariffs or other financial incentives for renewable energy technologies (including tax credits);
- carbon emission reduction targets;
- the availability of alternative financing options;
- air pollution concerns; and
- energy security concerns

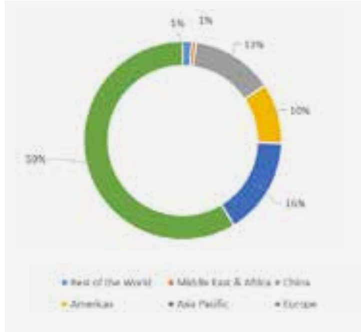
PV systems provide a clean and increasingly affordable option for building owners and occupants to produce their own electricity.

Globally, investments in small scale PV installations increased consistently between 2006 and 2012. This trend is expected to continue going forward, and it is estimated that solar PV installations could total 403GW by 2020.

Breakdown of capacity installed in 2000

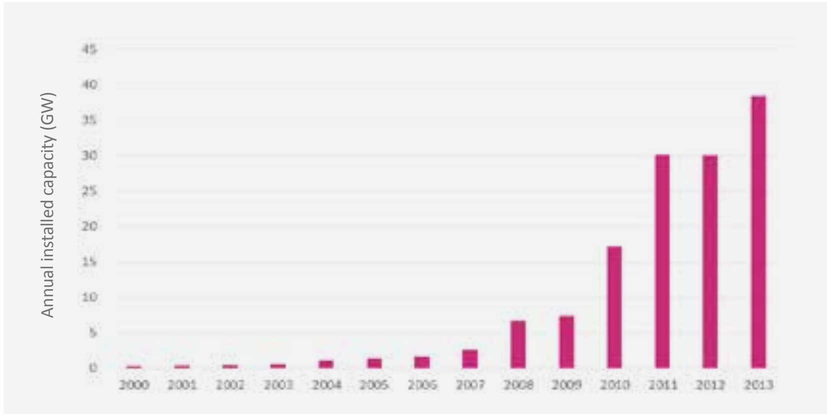
Source: EPIA, 2014

Breakdown of capacity installed in 2013



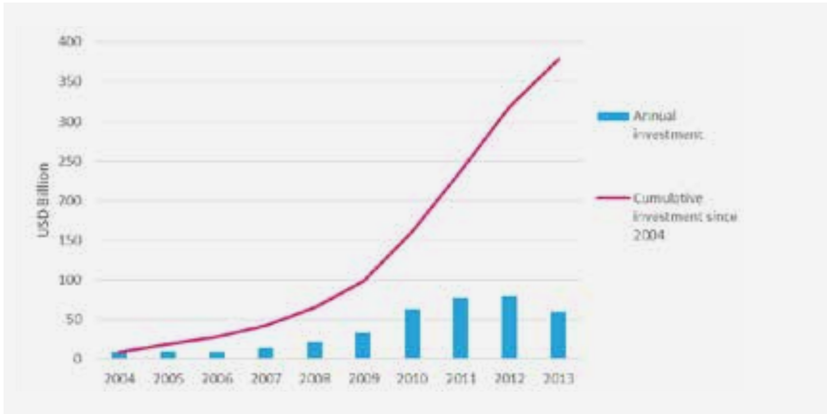
Source: EPIA, 2014

Installed capacity (GW)



Source: EPIA, 2014

Small (<1MW) distributed PV capacity investment



Source: BNEF

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PV system costs

Technical advances and increased demand and associated economies of scale have led to reduced system costs for PV modules and balance of system components.

The cost of installing a PV system is driven by the cost of the following:

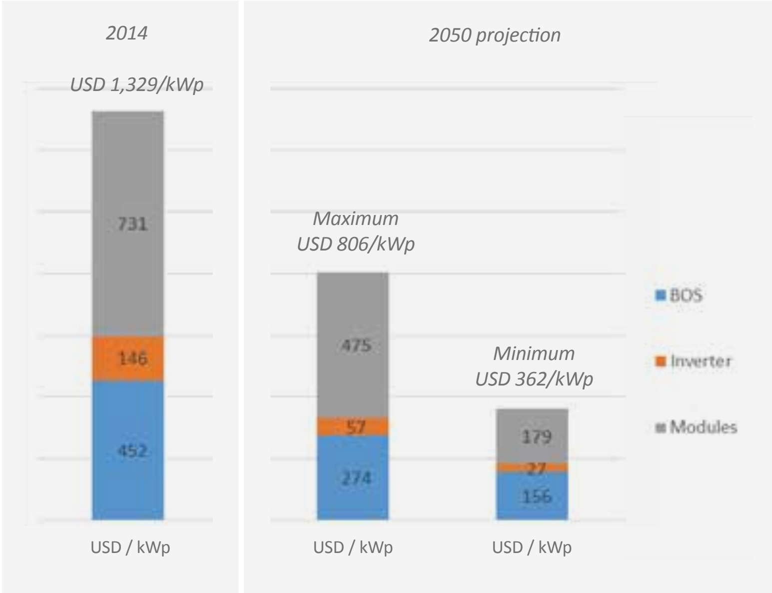
- PV system component costs;
- project development costs; and
- installation and commissioning costs

System components make up the majority of the overall capital cost, with modules and inverters accounting for more than 60% of total costs. Balance of system (BOS) costs include the mounting system, electrical equipment (such as transformers and cables), grid connection, installation and planning costs.

Overall installation costs for PV technologies have decreased significantly in recent years; the cost of generating electricity from crystalline PV modules, for example, has dropped by approximately 53% since 2009. This does not include any backup supply options, such as batteries or generators.

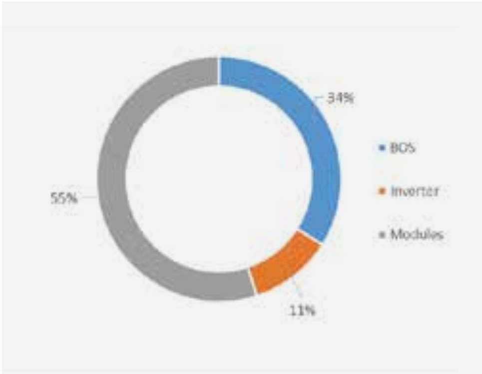
This trend is expected to continue going forward and overall system costs are forecasted to decrease by between 40% and 75% by 2050, compared to 2014 costs.

Utility scale PV system installed cost projection



Source: F-ISE

Breakdown of utility scale PV system installed costs, 2014



Source: BNEF
USD/EUR Average exchange rate for 2014 applied – OANDA.com

Global pricing trends

Overall system cost reductions, together with increased demand and associated manufacturing capacity, has led to significant decreases in the price associated with solar PV.

Grid supplied electricity tariffs have been increasing globally and the margin in price between PV and traditional electricity generation sources is therefore decreasing. In many markets, PV has reached retail electricity price parity, and given the recent trend for increasing grid supplied electricity tariffs, this trend is expected to continue.

This is therefore resulting in commercial and industrial electricity consumers (often on retail tariffs) viewing small scale, grid connected PV systems as increasingly attractive investment options.

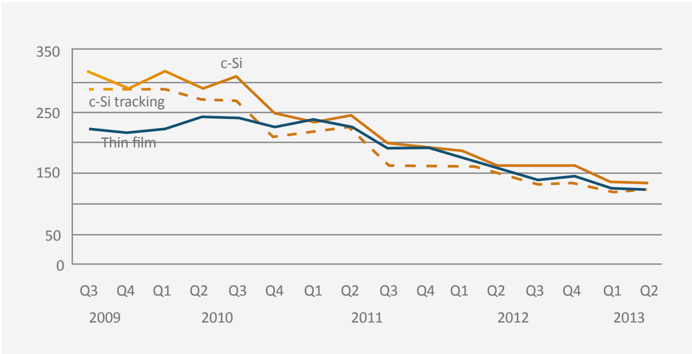
Country specific examples

Recognising the rapid cost declines being achieved in the PV sector, the German government reduced their Feed-in Tariff financial incentive for rooftop PV in 2012 by between 32% and 37%. The installation rates are expected to remain stable despite this, with installations of between 2.5GW and 3.5GW expected on an annual basis.

In South Africa, through a utility scale government procurement programme (REIPPPP), the average solar PV tariff for utility scale facilities dropped by two thirds over three competitive bidding rounds, in the space of three years. Round 3 prices reached approximately USD85/MWh.

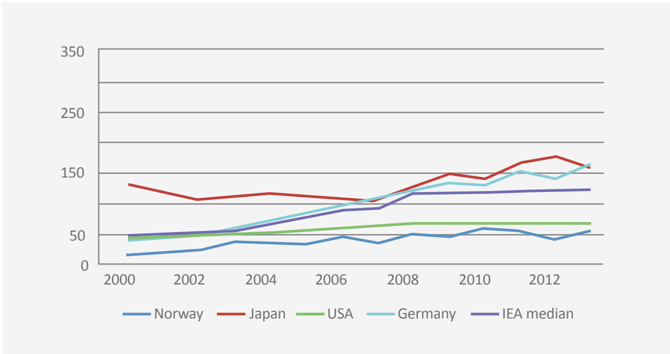
The USA has also seen consistent PV cost reductions, with installed system costs decreasing by 10-14% from 2010-2011, 6%-14% from 2011-2012, and by 12%–15% from 2012–2013 (dependent on the system size).

Levelised cost of PV electricity (USD/MWh)



Source: WEC

Blended electricity tariffs (USD / MWh)



Source: IEA

Solar energy conversion

The performance of a PV system is influenced by the amount of solar energy available at a specific location and by the effectiveness of the system to convert solar energy to electrical energy.

Global horizontal irradiation: The quantity and quality of the solar energy resource differs depending on the location of the desired site. This influences the amount of energy that the system can generate.

Solar resources databases are used to model the system's energy yield. Various data sets are available, providing historical solar irradiation data. Caution should be used in the selection of the database, as the confidence and resolution of the data can differ significantly depending on the source.

Module efficiency: Solar module efficiency (its effectiveness in converting solar energy into electrical energy) continues to improve through advances in research and development. Modules in operation typically have an efficiency of between 9% and 22%; however, module performance typically deteriorates over time. This module degradation can occur at a rate of approximately 0.3% to 1%/year, depending on the module type and local conditions.

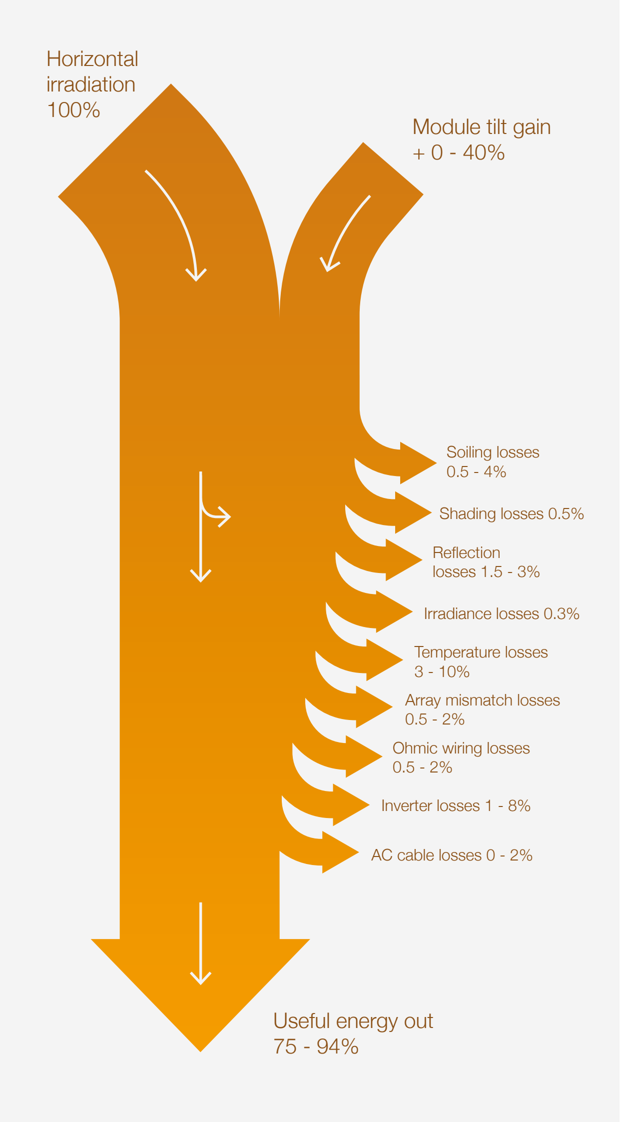
Energy loss during operation: There are losses associated with the individual components of the system, as the energy is converted from solar to electrical energy. These losses are inherent in all PV systems, but can be reduced through appropriate design considerations such module layout and spacing, cable lengths and inverter sizing.

Operations and maintenance programmes are also important to avoid increasing losses over time and activities such as module cleaning and inverter maintenance can have a significant impact.

Shading losses: Inter-row shading and the surrounding landscape influences how much exposure the system has to the sun. Neighbouring buildings, trees or natural features can shade part or the whole of a system, affecting overall energy generation.

*The gains that can be achieved from optimising the module tilt vary significantly, depending on the location of the installation, particularly the latitude.

Typical energy losses and gains during operations (after module energy losses are deducted)



Source: Arup analysis

PV module types

Poly-crystalline, mono-crystalline, thin film modules and mono/thin film hybrids are used in PV installations. Each of these modules have different properties, which influence the suitability of their application.

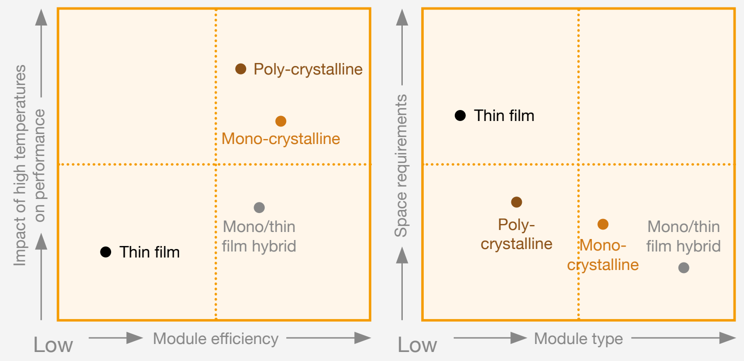
Poly crystalline modules are widely used with many proven manufacturers around the world. They are typically less expensive to produce than mono-crystalline modules, but are not as efficient.

Because of the way they are manufactured, Mono crystalline modules have a higher efficiency than most other types of modules, but can be more expensive as a result.

Thin film modules are made with a variety of different substrates (typically CIGS, CdTe and a-Si). While they require more rooftop space for installation than both types of crystalline modules, they typically cost less to produce. Thin film modules manufactured using heavy metals need to be disposed of in an appropriate environmentally sensitive manner. Most thin film manufactures are increasingly favouring CdTe and CIGS modules, with an increasing focus on the utility scale market. Flexible thin film modules (typically a-Si) are generally only used in small scale applications and are often not easily available for larger projects.

PV module performance decreases as ambient temperatures increase. Thin film modules typically perform better in hot weather, but the impact of high temperatures should be factored into the system design, and accounted for in facility yield analysis.

Mono/thin film hybrid modules combine the benefits of both types of modules; the performance under higher temperatures with the efficiency of crystalline modules. In general the impact of shading on modules needs to be considered. Depending on the module type selected, partial shading of the module can render the whole module ineffective.



Typically modules come with a 10 year mechanical warranty on the product, and a 25 year performance warranty. This performance warranty can either be of a 'step' or 'linear' type. Most module manufacturers are moving towards the linear warranty as module performance becomes more predictable.

Rooftop mounting system

Different roofs require different mounting solutions. While PV systems add a relatively low additional load on a roof, it is still important to ensure that the overall system is in line with structural allowances, and that it does not compromise the building's weather-proofing.

For rooftop installations, the module mounting system selected is dependent on the roof type and the structural characteristics of the building. Systems that track the sun are also possible, but these are more common in ground mounted installations. They typically cost more, are more technically complicated and require additional maintenance.

For buildings with a profiled roof sheeting (often industrial facilities), the mounting system can often be clipped on, without any drilling required. Ballast systems or low-pitch, low-ballast aerodynamic structures, can be used on flat roofs, similarly without any drilling required. For tiled roofs, bespoke mounting clips can be used that attach to the supporting structure under the tiles. Where these options are not available, it is possible to drill into the roofing material to attach the module structure.

Building designers and engineers are considering solar PV installation requirements more frequently during the upfront structural design and roofing material selection. This generally makes installation of solar modules easier and cheaper on new buildings, and allows systems to be scaled up as additional funds become available.

Key technical considerations:

- Penetrative mounting systems may compromise the building's waterproofing, and this may have an impact on waterproofing and roofing warranties.
- The building's structural integrity should be assessed, to determine that the additional load will not exceed the building's allowable loading limits. This should be considered during design, but also during installation, particularly when concrete ballasts are grouped and stored in a lay down area.
- The system's layout should consider local health and safety requirements, including whether or not access is required by emergency services in the event of a fire. This also affects accessibility for system maintenance, cleaning the modules, and carrying out maintenance on any of the components.
- The mounting system should be able to withstand applicable wind and/or snow loading.
- As the mounting system will be exposed to the elements, it is important that the material selected is adequately treated to prevent corrosion.

Building integrated PV systems

PV modules can be incorporated into the building's façade, serving a dual purpose of producing electricity and enhancing the building's aesthetic features by replacing traditional building materials.

Engage experts as early as possible in the design process: Competent practitioners can help to deliver solutions which are practicable, and which blend seamlessly with the architecture and surroundings.

Solar technologies get hot, so consider the adverse impact on internal spaces: An unventilated vertical BIPV system can have surface temperatures 40°C above ambient; the heat will be transferred to the internal spaces of buildings unless careful design of the thermal fabric is considered.

Design for access after installation: Solar technologies require cleaning, inspection and maintenance, and may need to be replaced altogether. Failure to design for access can impact on operations and maintenance costs.

Use "off the shelf" products: While a bespoke dimensioned solar technology may fit perfectly with the building's existing façade, it will likely be more costly to procure, replace and guarantees may be limited. Standard dimensions should be considered in the vast majority of cases.

Consider the suitable façade construction and solar technologies together. Whether a curtain walling, stick or other system is being considered for a building, make sure that the solar technologies fit seamlessly into the procurement and construction of the façade.

For the highest energy performance, the horizontal or slightly tilted facets of a building are the best: Vertical façades receive less solar energy than horizontal elements of a building. If the performance of the installation is the priority, it is recommended that horizontal surfaces are prioritised. Using vertical facets can, however, help to maximise total exposure to the sun, if gross energy production is prioritised over relative system performance.

The invisible benefits of solar technologies: Solar technologies can be an architectural material, defining the building. There are other, less tangible benefits, such as the visibility of the system to the surrounding community. BIPV systems can have a stronger physical presence or impact than a rooftop system, when installed on public facing sections of the building envelope.

Electrical equipment

The electrical equipment used in a PV system is important in ensuring that the system operates at an optimal level.

Inverters convert direct current (DC) to alternating current (AC) and they are required if PV systems are to be integrated with an AC electrical network. The design of any PV system should consider local standards and regulations, as this will influence the type of inverter that can be used. The size of the inverter, its efficiency rating and the operational environmental conditions will all influence the performance of the PV system. Single phase or three phase grid connected or islanded inverters can be used, depending on the overall load requirements. Systems are generally modular and system sizes can typically be easily increased as a result.

Solar inverters often have a special control capability, called maximum power point tracker (MPPT) which allows it to optimise current and voltage settings in order to maximise the output power.

Inverters are not always required for systems with only DC loads; however a DC to DC voltage converter may be required, depending on the load requirements.

Cables transmit power from the modules to the string boxes and inverters; and from the inverter to the building or grid. Rooftop cables are typically exposed to the environment, and should therefore be able to withstand UV light, ozone, heat and rain or hail without degrading. Cables used in PV installations are specifically manufactured to be UV resistant.

In general, cables with a larger diameter result in lower losses. They do, however, cost more. The benefit from lowering energy losses should be compared to this additional cost. Designing the system to minimize the necessary cable length will also help to reduce losses and will reduce overall capital costs.

String boxes: Inverters have a limited number of inputs (often two or three). String boxes are used to aggregate the inputs from multiple modules, so that more modules can be grouped together as inputs for each inverter. String boxes are often off the shelf products.

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The level of lightning protection incorporated into a PV system is dependent on the lightning strike density of the area. Surge protection devices can protect equipment from induced surges resulting from lightning strikes or grid events. Lightning rods on rooftops may be required to protect the system, but the cost of installing these should be evaluated against the expected benefits. In addition, the proximity of the lightning rods to the modules should be considered, as hot spots in modules can result from partial shading. The use of frameless modules increases the likelihood that the system will require external lightning protection.

All equipment should be adequately earthed, in accordance with local standards, in order for the system to operate safely.

Power transformers are used to alter the voltage level in order to match that of the building or grid. The type or rating of the transformer will depend on the offtake voltage level.

Controls and monitoring equipment

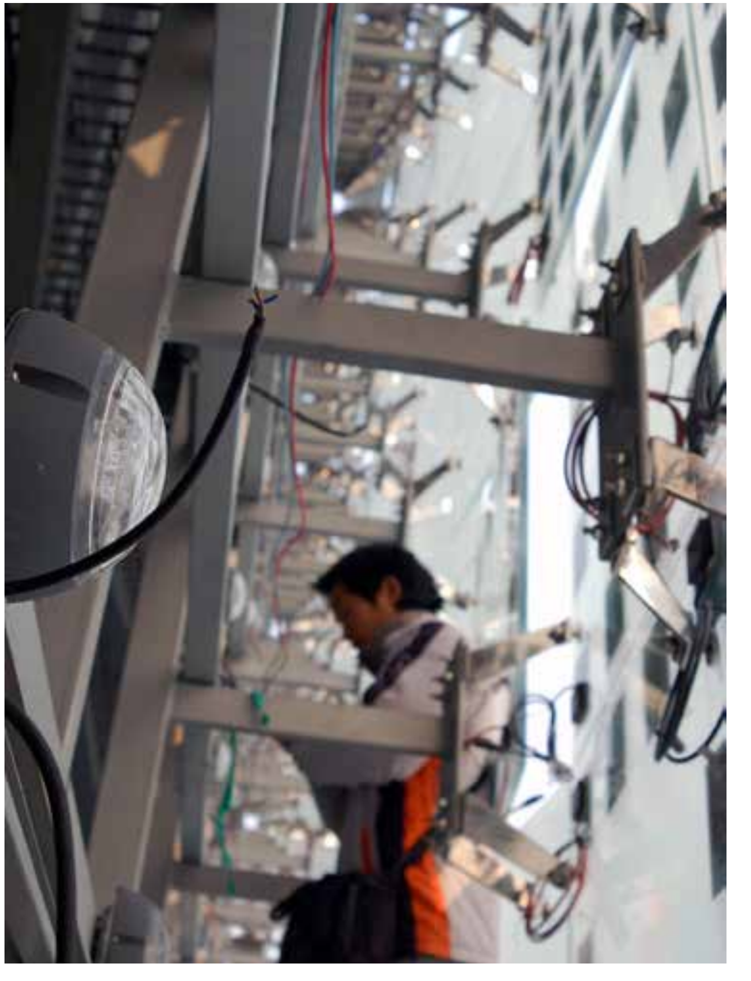
The electrical equipment used in a PV system is important in ensuring that the system operates at an optimal level.

Energy meters measure electricity generated by the system, and this data is used in assessing facility performance. If required, they can also measure and monitor peak power output, reactive power performance and the system's power factor setting. Many inverters are also able to record this data on an individual basis, allowing for performance monitoring of a portion of the facility. Data can be available for remote analysis, feeding into the facility's control.

The performance of a system is dependent on the environmental conditions. Weather stations measure and track temperature, insolation and wind speeds, so that the performance of the system can be compared to what should have been generated, given the conditions. Pyranometers or reference cells, anemometers and thermometers are all common in PV installations.

System controls are vital in ensuring the system operates efficiently. A utility may require system controls in terms of power output reduction, reactive power generation and absorption, and power factor correction capabilities. The grid code or regulations will inform what the system controls need to be able to do. For islanded installations, the system controls help to balance and optimise energy supply options.

Micro-inverters can also be integrated within a module. This to convert DC power to AC power at the module itself. Each module can therefore be monitored and controlled individually. This could result in the entire system having better performance, particularly under shading.



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Balancing supply and demand

The generation of electricity by a solar PV system can be intermittent; influenced by the time of day and the weather. This needs to be balanced with the building's demand profile.

Exporting electricity to the grid: During periods where electricity generated exceeds that of the building's demand, excess electricity could be fed back onto the grid. Local regulations should be adhered to, and special approvals may be required. The system should be designed to ensure that reverse feed is only possible when the grid is live. Health and safety becomes a concern during grid maintenance, when personnel may be in danger if grid connected generators are still generating electricity.

Demand response: If electricity cannot be fed back onto the grid, PV systems are best suited to facilities where electricity consumption is consistently high during the day. By monitoring a facility's overall load profile, it is possible to design a system size where it is unlikely that the generation will exceed the facility's electricity requirements. The building would need to be operating for seven days per week in order to avoid generating excess electricity on the weekend. If reverse feed is not permitted, overall power output would have to be reduced or curtailed.

Combining PV with other energy supply options: To maximize the use of generated electricity, particularly where the grid cannot be used for reverse feed, or in situations where there may be no grid at all, solar PV systems can be integrated with other energy supply options.

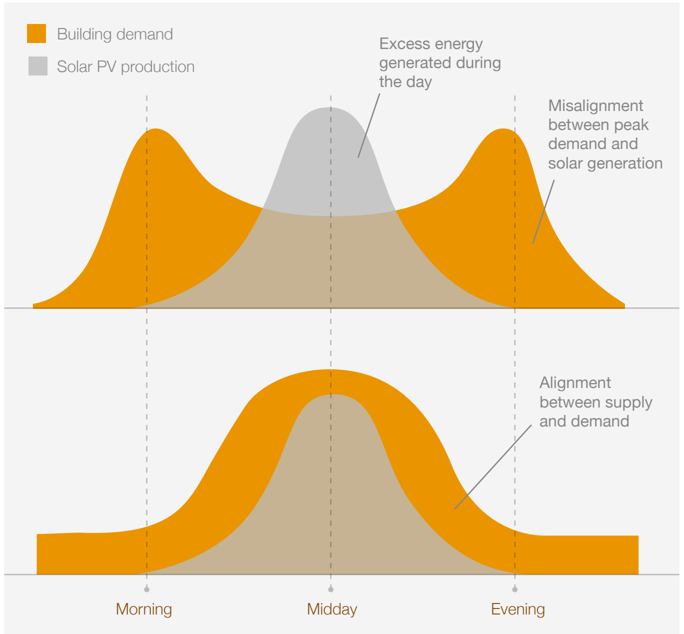
PV integrated energy storage options: Batteries, for example, are becoming increasingly common, as they help to shift electricity generated during the middle of the day to morning and/or evening peaks.

Electric vehicles complement solar installations well, as excess power during the day can be used to supplement transport energy requirements. It is also possible for electric vehicles to feed power back into the grid, which can assist with peak load levelling.

Solar PV can also be integrated with conventional distributed energy supply options, such as diesel or gas generators, to offset the amount of fuel required.

Off-grid systems can combine all three technologies; solar PV, batteries and generators.

Such hybrid systems require more complex control systems, but increase the building's energy independence and autonomy and mitigate against the intermittency of solar reliant generation.



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Installation and commissioning

Careful management of installation and commissioning activities will help to ensure that the project is completed safely, on time, to an acceptable standard of quality, and within the required budget.

There are many individual components that make up a PV system, and managing the procurement, delivery and installation of each requires planning and control. Modules, inverters and transformers may have long lead times, and equipment being imported may be subject to import duties, or require adequate time for import inspection, processing and handover.

The manufacturers will have requirements as to how the equipment is handled, transported and stored, and these should be complied with to avoid negating any warranties. This will also help to avoid damage to sensitive or fragile equipment.

Health & Safety considerations should be the first priority during installation. It is important that installers take care not to exceed the building's maximum loading limits at any point during installation. Equipment lay down areas on rooftops should be considered in the installation method statements, particularly where concrete ballasts are used.

PV modules are live from the moment they are exposed to sunlight. The method of connecting and disconnecting cables should be carefully managed. Arcing can occur when cables are disconnected under load, and all connected electrical equipment should be considered to be live, and treated with due care, by adequately trained installers.

Quality control, and the inspection of the installation is very important in preventing risks associated with poor installation quality. All installers should maintain records of inspections, and the installation of the system as a whole should be certified by a suitably competent professional.

Installation method statements should be prepared before any work commences and the installer is to ensure that all activities are done in accordance with these.

Commissioning and testing of the system is carried out to demonstrate mechanical completion and to test the installation's performance.

Typical tests include:

- mechanical completion tests;
- grid connection tests (if applicable);
- equipment functionality tests; and
- overall system performance tests (including performance ratio calculation)

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Operations and maintenance

The efficient operation of the system depends on timely and appropriate maintenance activities.

PV system components warranties typically require that the equipment is operated and maintained under specified conditions. Should these conditions not be fulfilled, warranties may be void.

It is important to understand the equipment manufacturer's operational requirements. These may relate to the housing of the equipment, the minimum and maximum ambient temperature, the humidity or level of dust, or the type and frequency of maintenance activities.

Inverter components, or the entire inverter, require replacement during the operational life of the plant. They can be a material component of the upfront capital costs, and this should be considered in the estimation of operational expenditure.

A PV system's performance is most commonly monitored by tracking its Performance Ratio. This is the ratio between the actual energy generated by the system as a whole, compared to the theoretical maximum energy that could have been generated, for a defined period of time.

Ineffective maintenance leads to increased losses, resulting in lower system performance or safety hazards.

Contracting strategies

Rooftop leasing arrangements

In this arrangement, the rooftop is leased/used by a third party.

Electricity generated can either be consumed by the building occupants with spare electricity exported to the grid or electricity can be exported in its entirety to the grid.

Where consumption takes place on site, parties enter into an agreement for the purchase of electricity. The cost of electricity could be:

- fixed for the duration of the agreement;
- indexed by inflation; or
- linked to the utility price

Typically savings are realised from the outset and the ownership of the system can be transferred to the building owner after defined conditions have been met.

Where all electricity is exported, the ownership of the system typically remains with the installer and the financial transaction between the parties is for the use of the roof only. The system owner enters into an agreement with the off-taker for the sale of electricity and remains responsible for the operations and maintenance of the system.

The O&M of the system is the responsibility of the third party until transfer of ownership.

The interface between two parties is the roof.

Accessibility, protection of the roof, system and building, and the system insurance requirements are to be considered.

Design and build agreements

The building owner commissions the design and construction of the system, possibly from two separate parties.

Owner involvement is important, and oversight of each stage is required.

O&M can be carried out by the owner or by appointed third parties.

No guarantee on system performance and changes to the design can lead to contract variations.

The overall capital cost may be lower, but the owner takes on cost, schedule and performance risk. There are multiple parties interfacing with one another which also poses a project risk.

This contracting strategy requires effective contract management and the training of maintenance staff.

EPC / O&M contracts

All design, procurement, construction and commissioning work is carried out by the Engineering Procurement and Construction Contractor (EPC).

O&M is carried out by the O&M Contractor.

Facility performance obligations should be in place, and penalties should be payable if the system underperforms.

Minimum owner involvement required.

The EPC takes on design, cost, schedule and performance risk. Structural and electrical risk resides with the EPC. The overall project cost is therefore increased.

Possible interface risks between EPC and O&M during defect liability period.

Financial support and incentives

Funding for the procurement and installation of PV systems can be supported by financial incentives and subsidies, depending on local government's policies and priorities.

Tax incentives

Tax incentives could be in the form of:

- an allowance for accelerated depreciation of a renewable energy asset;
- a reduction in corporate tax liabilities resulting from additional profits realised through the installation of alternative energy options; or
- production tax credits for installing renewable energy technologies

Upfront grants or favourable loans

Subsidies can be provided through upfront capital support. Financial institutions with a developmental mandate may be empowered to provide loans at a below-the-market interest rate in order to stimulate market growth. In addition, support can be provided by taking on exchange risks in emerging markets or allowing for a grace period in the repayment of loans.

Indirect incentives

Indirect incentives, such as carbon taxes on fossil fuel based generation, also promote the use of renewable energy technologies over traditional electricity generating options.

Preferential tariffs

Guaranteed price support mechanisms, through independent power producer programmes or government payment programmes, could take the form of Feed-in Tariffs or Contracts-for-Difference agreements. The electricity generated by the system would be sold at preferential rates to the off-taker.

Mandated quotas

Government procurement may include a minimum allowance for renewable energy technologies, helping to stimulate the local market, establish consistent and predictable demand, and helping to lower overall system costs as a result.

Mandated carbon emission quotas also influence investment in renewable energy technologies. Organisations with mandated carbon targets can either invest directly, or procure carbon credits.

For more information
please contact:

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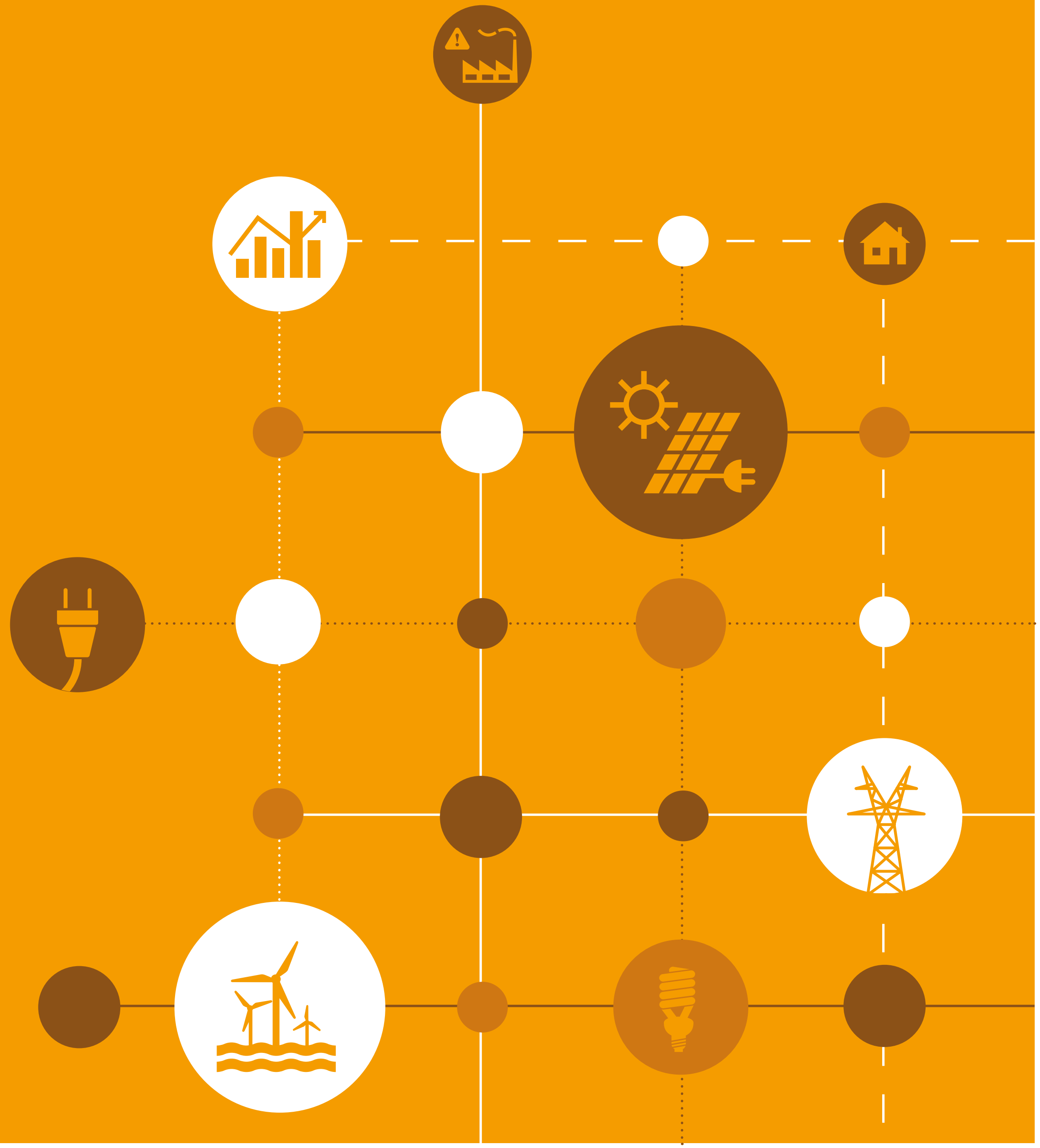
www.arup.com



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