White Paper March 2026

System-Compatible Integration of Photovoltaics

swissgrid

Contents

Introduction

As the national grid company, Swissgrid is responsible for ensuring the non-discriminatory, reliable and efficient operation of the transmission grid. In doing so, Swissgrid is laying the essential foundations for ensuring a secure supply of electricity for Switzerland. Even though no photovoltaic (PV) plants are connected directly to the transmission grid[1] in Switzerland, the rapidly growing feed-in from photovoltaic plants affects the electricity system in many ways. Swissgrid must coordinate these interactions. The shift in the power plant park away from large-scale power plants towards large numbers of decentralised, inverter-based small-scale installations also has a significant impact on the behaviour of the electricity system.

To ensure that Swissgrid can continue to guarantee the secure and reliable operation of the transmission grid at all times in the future, it is vital for PV expansion in Switzerland (regardless of the grid level) to be carried out in a grid-friendly way that supports the system. Swissgrid is committed to integrating PV in order to facilitate the implementation of the energy strategy on the grid side, to minimise the costs of grid expansion and to ensure long-term system stability.

Swissgrid has launched the initiative behind this white paper to complement the other initiatives already in place in the Swiss electricity sector – which primarily focus on the short-term adaptation of processes and regulations (e.g. electrical industry documents). The aim of this white paper is to conduct a comprehensive systemic analysis of the challenges involved in integrating photovoltaic plants in line with the targets set out in the Electricity Act, and to suggest the necessary (long-term) measures to ensure successful implementation from a systemic perspective.

The «System-Compatible Integration of Photovoltaics» white paper is intended to serve as a catalyst and a basis for discussion on the expansion and integration of PV in Switzerland for all the players involved. The suggested measures are designed to provide input for the adaptation of processes and specifications within the electricity sector and to serve as recommendations for policymakers and public authorities.

[1] The Swiss transmission grid – also known as the extra-high-voltage grid – constitutes what is referred to as grid level 1 and is generally operated at voltage levels of 220 kV and 380 kV. Generating plants may be connected directly to the transmission grid, provided they have a capacity of at least 150 MVA.

The chosen approach focused on establishing a temporary group of experts led by Swissgrid. This group of experts comprises selected specialists from the Swiss energy sector who have extensive experience in the integration of photovoltaic plants. The members of the group represent different perspectives and roles within the energy system (e.g. distribution system operators, balance group managers[2], market players and PV industry representatives) and offer individual expertise and insights. However, they were not nominated as official representatives of their respective companies (in other words, this document does not necessarily reflect the official views of their organisations).

This document could not have been prepared without the constructive, respectful and open-minded collaboration of these experts.

Expert	**Position**	**Organisation**	**Perspective**
Dr Christof Bucher	Professor of Photovoltaic Systems	Bern University of Applied Sciences	PV research
Dr Turhan Demiray	Research Director	Research Center for Energy Networks – ETH	Network research
Dr Andreas Ebner	Managing Director Business Unit Grid Planning and Projects	BKW	Distribution grid
Matthias Egli	Managing Director	Swissolar	PV sector
Holger Feser	Senior Originator	Alpiq	Regulation, market
Thomas Reinthaler	Head of National and International Relations	Swissgrid	Transmission grid
Alice Scho-Freise	Head Dispatching & Balancing	Axpo	Balance group

[2] A balance group is a virtual construct for the purposes of billing and accounting. Every Swiss feed-in and outflow point (e.g. power plants and end consumers) is assigned to exactly one balance group, under the responsibility of a balance group manager (BGM). All energy feed-ins and feed-outs, as well as energy transactions, are consolidated and settled through a balance group.

Summary

Switzerland is in the midst of a comprehensive transformation of its energy system. Photovoltaic (PV) production has become a cornerstone of Switzerland's electricity mix and is set to play a key role in the implementation of the Energy Strategy 2050. With around 1.8 gigawatts (GW) of new PV capacity installed in 2024 and a cumulative total capacity of around 8 GW, photovoltaic plants supplied approximately 10% of Switzerland's electricity consumption in 2024 – and a share of 14% was expected for 2025.

However, the rapid expansion of PV also presents significant challenges, as its integration into the Swiss electricity system has not yet been addressed using a holistic approach. These challenges are further exacerbated by the highly decentralised structure of photovoltaic plants (mostly small and medium-sized rooftop systems) and the high degree of fragmentation within the Swiss electricity sector. The challenges include ensuring system operation, grid connection, grid expansion and long-term grid planning, the cost-effectiveness and market integration of photovoltaic plants, data availability, and finally, flexibility and storage requirements.

Given the current processes and framework conditions, it is hard to imagine integrating up to 40 GW[3] of installed PV capacity into the Swiss electricity system.

That is why Swissgrid launched the initiative to produce this white paper, with a view to developing measures that will enable the system-compatible integration of PV.

Based on the challenges identified and the specific areas of action defined, Swissgrid is suggesting a comprehensive package of measures covering different timeframes, players and levels of detail. Consistently combining specifications, market signals, incentives and processes is the only way to integrate up to 40 GW of installed PV capacity.

Below is a selection of some of the key measures suggested:

- **Secure system operation:** Although large, centralised power plants are being phased out and electricity generation is becoming more decentralised, Swissgrid must continue to have sufficient resources available at all times to ensure secure system operation (frequency maintenance, voltage maintenance and dynamic stability). The loss of (stabilising) rotating mass must be compensated for by other systems. It needs to be clarified whether this can be ensured in part through decentralised production and storage itself. To make this possible, appropriate framework conditions (such as minimum requirements and standard settings) must be established for these systems.

  In addition, standardised guidelines are needed (including effective implementation) for photovoltaic plants to govern their behaviour in the event of communication faults or grid outages and in relation to cybersecurity.

- **Reduced grid connection:** Dimensioning the grid to accommodate 100% of the installed PV capacity (i.e. up to 40 GW) makes no sense, either technically or economically. Distribution system operators should be given the option to agree to a more extensive[4] long-term reduction in grid connection capacity in exchange for remuneration. The limitation will be applied at the grid connection point – the system owner can either consume or store the energy that cannot be fed into the grid. This measure does not mean that the energy is simply «wasted». Even if the grid connection is reduced to 50% of the installed PV capacity, this would only result in around 15% of the energy not being fed into the grid over the course of the year.

[3] The SFOE's Energy Perspectives 2050+, published in 2021, already envisage an installed PV capacity of 37.5 GW for 2050 in the ZERO Basis scenario.
[4] The current legislation, in conjunction with the VSE electrical industry document, allows the grid connection to be limited to 70% of the photovoltaic plant's installed DC capacity.

- **Feed-in follows market signals:** The decision on how and where to use or sell the electricity generated by photovoltaic plants should be market-driven, i.e. it should respond to supply and demand. If the market price is negative, there should be no financial incentive to feed electricity into the grid. In order to ensure the best possible market position for the electricity generated by PV, the most appropriate option appears to be to replace the local supplier's current obligation to purchase PV feed-in with an obligation for the system operator to appoint a trader. Optimising own consumption and promoting local consumption (for example via ZEV and LEC) should represent key sources of revenue for photovoltaic plants. Another key source of revenue that is expected to make a greater contribution to the payback of investments in the future is the marketing of flexibility (i.e. the adjustment of the prosumer's production and consumption[5]).

- **Focussing on capacity rather than maximising annual yield:** Although sufficient electricity is already generated at certain times of the day (particularly in the summer), no structural surplus in production is foreseeable in Switzerland in the winter, even in the long term. If PV is to make a significant contribution to a secure electricity supply even in winter, the installed PV capacity (kWp) must be increased even further – as envisaged in the Energy Strategy 2050 – even though not every kilowatt-hour (kWh) of electricity generated is needed at all times. Incentives for expanding capacity should therefore be separated from operational incentives (i.e. when and how the plant is operated).

- **Only flexible systems are future-proof:** Due to the increase in the amount of electricity being fed into the grid simultaneously by photovoltaic plants, combined with market-based remuneration, revenues from feed-in are falling or even turning negative, particularly at times of high PV production (at midday during the summer months). To ensure that photovoltaic plants remain economically viable in the future, they must be able to respond flexibly to price fluctuations and the framework conditions governing both the system and the grid. Ideally, this can be achieved by combining the plant with a storage system and/or flexible behind-the-meter consumers (prosumers), including an energy and power management system. The flexibility of photovoltaic plants will therefore no longer be an option in the future, but a prerequisite.

- **Coordination and data interchange are crucial for the use of flexibility:** As more and more decentralised flexibility becomes available, there is a need for a uniformly defined end-to-end process for accessing this flexibility and the associated data interchange. This is necessary in order to manage the prioritisation of flexibility types, the cascading of flexibility requests between different players, and the interface with the system owner. Flexibility should be allocated according to a market-based approach; power system constraints must be taken into account. A central flexibility platform with a coordination mechanism appears to be the best implementation option. The «TSO-DSO Coordination» pilot project is testing how local flexibility coordination of this kind could be put into practice.

[5] By installing a photovoltaic plant, consumers also become producers («prosumers»).

Overview of key measures

Even decentralised production requires sufficient, reliable operating ressources to maintain system stability.

Remuneration for electricity fed into the grid should be based on market signals. Subsidies should be based on capacity (kWp).

«Future-proof» photovoltaic plants = systems combined with storage and/or flexible consumption behind the meter (prosumers).

Connecting 100% of the installed photovoltaic plant capacity to the grid does not make sense ⟶ the grid connection capacity should be reduced.

Sufficient installed capacity is required for supply. But not every kilowatt-hour of electricity generated at all times.

Decentralised flexibility must be coordinated: players must receive the necessary data in a timely manner, including prioritisation and cascading mechanisms.

These measures – together with the detailed recommendations for action set out in the white paper – are intended to encourage the relevant players, whether they are system owners, policymakers or public authorities, to safely drive forward the expansion and integration of PV into the overall system.

Source: BKW

Initial situation and approach

Initial situation

The importance of photovoltaics in Switzerland's electricity mix

Switzerland is in the midst of a comprehensive transformation of its energy system. Integrating a rapidly growing number of decentralised photovoltaic plants is a key part of the Energy Strategy 2050. In recent years, PV has evolved from a niche technology into a cornerstone of Switzerland's supply of electricity. In 2024, a record was set for new installations, with around 1,800 megawatts (MW) of new PV capacity installed. This brought the cumulative installed PV capacity to 8,170 MW at the end of 2024, which represents 8.17 gigawatts (GW). This is roughly equivalent to Switzerland's current peak demand, or «peak load», in summer (around 7–8 GW).

Annual electricity generation from PV amounted to around 6,000 gigawatt hours (GWh) in 2024, which corresponds to approximately 10% of Switzerland's electricity consumption. A share of 14% was expected for 2025.

The number of photovoltaic plants in Switzerland rose above the 300,000 mark in 2025. The prevalence of small and medium-sized rooftop systems is a characteristic feature of the Swiss market. The average size of all the installed photovoltaic plants is approximately 25 kilowatts (kW). The median is around 11 kW. Around 40% of PV electricity is generated by systems with a capacity of less than 30 kW.[6]

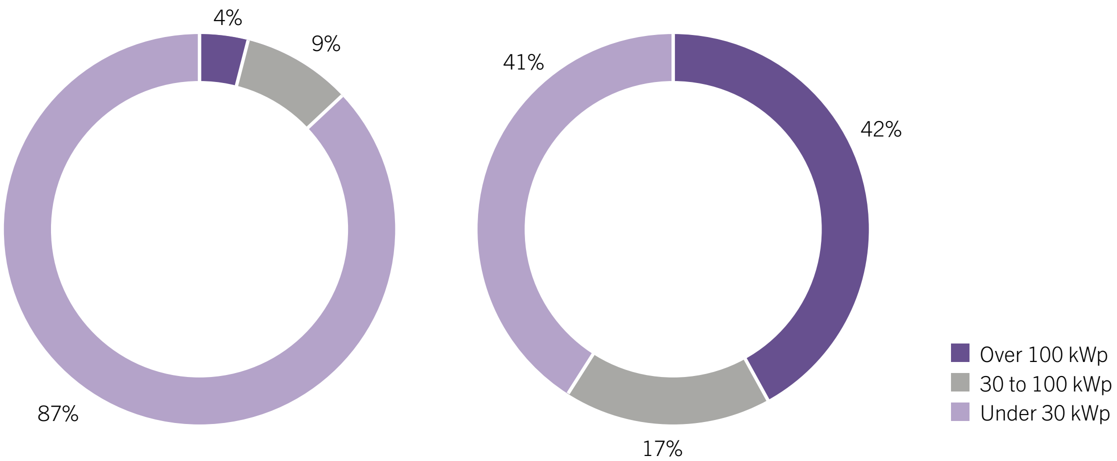
The proportion of photovoltaic plants with battery storage is also rising steadily. It has now become standard practice to combine new photovoltaic plants with a battery storage system.

Political and legal framework conditions

On 9 June 2024, the Swiss public approved new electricity legislation («Federal Act on a Secure Electricity Supply from Renewable Energy Sources») by a margin of almost 70%. This Act sets out binding and ambitious targets for the expansion of renewable energy:

- **By 2035:** At least 35 terawatt-hours (TWh) of electricity per year from new renewable energy sources (excluding hydroelectric power)
- **By 2050:** 45 TWh of electricity per year from new renewable energy sources (excluding hydroelectric power). According to the SFOE's Energy Perspectives 2050+, around 80% of this is expected to come from PV (around 34 TWh). This requires an installed PV capacity of 37.5 GW[7].

Number and installed capacity of photovoltaic plants by size



Number of photovoltaic plants
by performance category

Installed PV capacity
by performance category

[6] Source: Swissgrid, analysis of the Pronovo data base as at May 2025
[7] See SFOE, 2021 Energy Perspectives 2050+ – technical report, p. 318: ZERO Basis scenario; installed PV capacity of 37.5 GW

The legislation sets out a number of measures to achieve these objectives:

- **Subsidy schemes:** The current subsidies, such as one-off remuneration and feed-in tariffs, will be extended and harmonised until at least 2035. The remuneration for feeding solar power into the grid is based on the market price, but combined with minimum remuneration.

- **Virtual pooling for own consumption (vZEV):** Since 2025, households or businesses have been able to link their electricity meters together virtually to optimise their own consumption.

- **Local electricity communities (LEC):** Since 2026, LEC have been able to pay lower charges for use of the public grid in order to supply each other with electricity they have generated themselves.

- **Mandatory solar plants:** New buildings with an eligible surface area of more than 300 m^2 are obliged to install solar plants (PV or solar thermal panels).

A rapid expansion of Switzerland's PV capacity is expected to occur as a result of these political guidelines. According to current growth forecasts, installed PV capacity is set to almost triple over the next ten years.

On 26 November 2025, the Federal Council approved the partial amendments to the Energy Ordinance and the Renewable Energy Ordinance, including interim targets for the expansion of renewable electricity generation in Switzerland by 2030. A target of 18.7 terawatt-hours (TWh) was set for PV for 2030, which confirms the scale of the capacity targets mentioned above.

Problem and approach

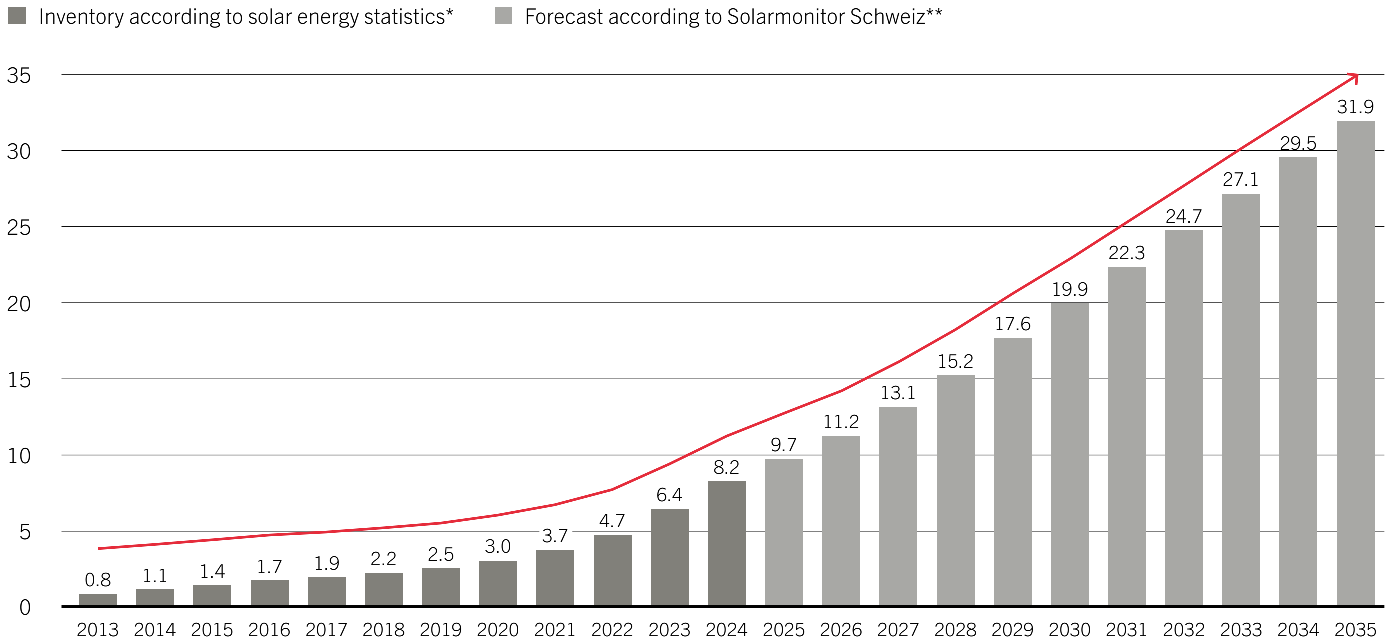
The strong growth in PV capacity is both welcome and necessary for implementing the Energy Strategy 2050. However, this also results in significant challenges for the integration of PV into the Swiss electricity system, as the inclusion of PV is not yet optimal for the system. This challenge is further exacerbated by the highly decentralised structure of photovoltaic plants (mostly small and medium-sized rooftop systems) and the fragmentation within the Swiss electricity sector.

Aspects of these challenges include:

- Ensuring system operation despite the declining number of «traditional» large power plants in Europe and the associated reduction in the rotating, stabilising mass within the system
- Grid connection, grid expansion and long-term grid planning (particularly for the distribution grid)
- Economic efficiency and market integration
- Data availability and forecasting processes
- Flexibility and storage requirements, particularly to meet winter electricity demand
- Regulatory harmonisation and process adaptation

Development of PV expansion in Switzerland

Cumulative installed PV capacity in Switzerland (GW)



* Swiss Federal Office of Energy (SFOE): 2024 solar energy statistics, July 2025.
** Swissolar: SOLARMONITOR Schweiz 2024 – Entwicklungen, Trends und Perspektiven im Photovoltaik-Markt Schweiz, November 2024.

Objective

The aim of this white paper is to identify possible solutions to the following question:

«How can we create (technical, regulatory, economic and organisational) **framework conditions** that will enable us to integrate the expansion targets (focussing on PV) set out in the ‹Federal Act on a Secure Electricity Supply from Renewable Energy Sources› **securely and sustainably into the Swiss electricity system?»**

Procedure

The work of the group of experts comprised the following steps:

Procedure for producing the white paper

Analysis of current situation and challenges
PV integration

↓

Clustering challenges and definition **areas of action**

↓

Development of **measures** for each area of action

↓

Consolidation of measures & **recommendations**

Analysis of the current situation (challenges and causes)

A comprehensive analysis of the current situation identified **existing challenges** for integrating photovoltaic plants into the Swiss energy system. The causes of each challenge were also analysed.

Definition of areas of action

Based on the findings in relation to these challenges, a total of six areas of action were identified (see section areas of action).

- **(System) operation**
- **Energy sector and market**
- **Prosumers and system owners**
- **Grid infrastructure**

There are also two overarching areas of action: **«Controllability and incentives for the use of flexibility»** and **«Data».**

Development of measures for each area of action

In a subsequent step, the group of experts developed specific solutions for each area of action, with different timeframes for implementation (ranging from short to long term). In view of the long-term need to integrate PV, no account was taken of the current legal framework; in other words, measures were deliberately included that would require amendments to the existing legislation.

Consolidation of measures

Finally, the group of experts consolidated the measures to ensure that the suggestions are consistent and do not contradict one another, resulting in a feasible and workable overall framework that will allow the system-compatible integration of large-scale PV in Switzerland. This overall picture is presented in this white paper. It aims to provide input for ongoing discussions on adapting processes and specifications within the electricity sector and to serve as a recommendation for policymakers and public authorities.

Challenges

The integration of PV into the Swiss electricity system involves a wide range of challenges that can be divided into three main categories: grid and system operations, market and balance groups, and prosumers and system owners.

Grid and system operations

The rapid expansion of decentralised photovoltaic plants poses significant challenges for grid operators[8]. Grids which were traditionally designed for large-scale, centralised generation must now cope with bidirectional load flows and highly fluctuating patterns of electricity feed-in and feed-out.

Grid connection and expansion

According to the current absolute connection and purchase obligations[9], distribution system operators (DSOs) must dimension their grid infrastructure to accommodate maximum feed-in levels. The introduction of the statutory regulation on the guaranteed use of flexibility by DSOs in a way that benefits the grid from 2026 allows the grid connection capacity of photovoltaic plants to be reduced to 70% and represents an important step in the right direction. However, the lack of reliable options for flexible connections and dynamic feed-in limits continues to result in a need for grid expansion that is required for only a few hours a year. At the same time, grid expansion is proceeding at a much slower pace than PV expansion. Lengthy approval procedures, extensive red tape and regional planning obstacles for grid infrastructure stand in stark contrast to the rapid expansion of PV. In some cases, the installation of a new photovoltaic plant is now merely subject to notification – in line with the aim of ensuring the swift implementation of the energy strategy.

Access options and emergency control

In many cases, photovoltaic plants cannot currently be controlled remotely, or the existing control functions are not yet utilised to their full potential.

Emergency control by the DSO on the grid side is important for preventing local power failures. However, there are various obstacles to practical implementation:

- The highly diverse and fragmented landscape of grid operators in Switzerland
- No obligation for the DSO to implement emergency control
- Lack of standardised communication between the photovoltaic plant (or energy management system) and the DSO
- No standardised cascading of emergency control procedures among grid operators
- Technical failure to implement the legal provision stipulating that guaranteed flexibility that benefits the grid takes precedence over all other flexibility signals[10]

Furthermore, the DSO's grid-side emergency control system is neither designed nor suited to harnessing the flexibility of photovoltaic plants. What is more, there is currently no standardised interface that allows the various players and devices to communicate with one another.

Flexibility

Under the relevant legislation, the flexibility offered by a prosumer can be utilised by various players – TSOs, DSOs, suppliers and aggregators. Without adequate coordination, there is a risk of conflicting or overlapping activations, with no clear division of roles or prioritisation. Nor is there an established cascade for passing on control requirements between grid operators and system operators.

System operation

As the number of conventional large-scale power plants decreases, the rotating mass within the entire electricity system falls. However, the rotating mass inherently stabilises the system due to its inertia. The loss of the inertia associated with the decommissioning of large power plants is not yet being sufficiently offset by alternative sources. At present, there is no market that offers financial incentives for inertia, and there are no binding requirements for (small) plants.

Voltage maintenance in the distribution grid is a key aspect that must be taken into account when connecting photovoltaic plants. It is often a limiting factor. However, the impact of decentralised generation on the operation of the transmission grid in terms of voltage remains unclear. Furthermore, the technical potential of system-stabilising inverter and battery systems is still largely untapped, and there are no standardised guidelines.

In power generation, the high degree of simultaneity in PV production, combined with a low load (exacerbated by own consumption), can lead to an imbalance between supply and demand. This is currently reflected in the rising number

[8] As the national grid company, Swissgrid is the transmission system owner and operator (TSO) (220 kV and 380 kV voltage levels). Low-voltage grids are operated by the distribution system operators (DSOs). In this document, the term «grid operators» is used to refer to both TSOs and DSOs; otherwise, the specific role (either TSO or DSO) is explicitly stated.

[9] The connection obligation applies to all photovoltaic plants, whereas the purchase obligation applies only to plants with a capacity of ≤ 3 MW or an annual production of ≤ 5,000 MWh (Art. 15 para. 2 of the Energy Act)

[10] Art. 17c para. 5 of the Electricity Supply Act

of hours with negative prices. The storage capacities for daily and seasonal storage are insufficient, and there are not enough financial and market-based incentives for PV expansion in relation to the proportion of winter electricity and feed-in limits.

There are also cybersecurity risks: inverters (as well as other prosumer systems such as charging stations and energy management systems [EMS]) can increasingly be controlled remotely over the Internet. Inadequate regulations and a lack of awareness of the problem increase the risk that external players could destabilise the electricity system by accessing it in this way.

Market and balance groups

Forecasting and optimisation

Due to the rise in decentralised generation and consumption, Switzerland's current electricity supply landscape is reaching its limits, as many suppliers and DSOs do not have the necessary human and technical resources to meet the current challenges. Furthermore, there is very little cost pressure to optimise the system, as imbalance energy costs are included in the basic supply tariff. Poor forecasting quality is a major cause of significant imbalances within the balance groups. Forecasting is made more difficult by the frequent lack of access to the measurement data required to calibrate models. This also applies to the lack of «visibility» regarding production, storage and consumption behind the meter, which calls for innovative approaches to modelling and forecasting.

Data availability and forecasting models

For data protection reasons, if smart meter data relevant to billing is available, it is sent to the supplier only once a day with information from the previous day. Smart meters are not designed to meet the requirements of grid operation and are therefore not suitable for this purpose. Although internal measurements are available to the system owner, they are rarely used by other players. There is no overview of how data is used for forecasting and control. In addition, the high degree of fragmentation among suppliers and DSOs hinders the timely flow of information and data interchange.

Remuneration and marketing

In terms of remuneration, photovoltaic plants are often still subject to fixed feed-in tariffs with a minimum rate of remuneration. As a result, during periods of low or no demand – particularly when prices are negative – there is not enough financial incentive to stop feeding energy into the grid. Fixed feed-in tariffs also lead to the generation of the maximum energy volume – regardless of the season or demand. Suppliers and their balance groups lack the means to limit PV feed-in in a targeted manner. Where such control capabilities exist, they are the responsibility of the DSO, who may use control and regulation systems solely in a way that benefits the grid.[11] Purchasers of flexibility – such as balance groups, which are tasked with preventing imbalances, or flexibility traders – must set up their own control and regulation systems.

What is more, the Swiss intraday market often lacks the liquidity required to balance positions between balance groups when this cannot be achieved within the balance group itself. The lack of an electricity agreement prevents efficient access to the EU's intraday market (intraday market coupling).

At the same time, there are insufficient incentives on the consumer side, such as variable energy and grid tariffs, to align electricity demand with production. In addition, the consumption of electricity is still partly subject to old production patterns, and incentives have not yet been adapted to new production cycles such as night-time and low-load tariffs or ripple control signals

The current pooling concept for integrating decentralised resources into the ancillary services market (AS) has enabled aggregators to pool and market decentralised installations, but is not designed for large-scale roll-out.

Prosumers and system owners

Constantly evolving technical specifications and growing regulatory requirements are making the installation and configuration of photovoltaic plants more and more complex. Insufficient monitoring of the settings of installed photovoltaic plants is a major source of uncertainty in grid operations. There is no uniform communication standard for efficient building automation. Retrofitting existing systems is complex and costly, which makes it very difficult to implement the necessary standards and requirements across the board. The technical and regulatory framework conditions have not yet been adapted to the current situation, in which end consumers are becoming producers and providers of flexibility.

Interim conclusion: challenges

The challenges identified clearly show that the system-compatible integration of PV requires a coordinated approach involving all the relevant players. Many of the challenges are interlinked and can only be addressed by introducing a coordinated package of measures.

[11] Art. 19a of the Electricity Supply Ordinance

Areas of action

The following six areas of action have been defined in order to structure the various challenges and the necessary measures to overcome them:

The six areas of action

(System) operation	Energy industry & market	Prosumers & system owners	Grid infrastructure
Controllability & incentives for the use of flexibility			
Data			

«Data» and «Controllability & incentives for the use of flexibility» are overarching areas of action which have an impact on all the other areas. Generally speaking, it is not always possible to make a clear distinction between the individual challenges and measures – however, the definition of areas of action can help maintain an overview and consolidate measures. In specific terms, the following topics are addressed in the individual areas of action:

(System) operation
- Operational grid and system operation (voltage and frequency maintenance, congestion management, dynamic effects)
- Specifications for system operation
- Cybersecurity

Energy sector and market
- Market design for the purchase and sale of (PV) electricity (wholesale market, basic supply, minimum remuneration)
- Marketing of flexibility
- Coordination of the use of flexibility

Prosumers and system owners
- Installation and configuration of photovoltaic plants
- Cost-effectiveness of investments in plants
- Interaction between decentralised behind-the-meter flexibility (prosumers)

Grid infrastructure
- Connection of the agreed capacity to the grid, including grid dimensioning according to grid topology (urban/rural)
- Requirements for connecting plants to the grid
- Speeding up grid expansion in tandem with the expansion of generation capacity

Controllability & incentives for the use of flexibility
- Making flexibility available, coordinating its use and regulating access
- Incentives and the ability to control systems (remotely)

Data
- Data (master data and flow data) relating to photovoltaic plants and PV generation
- The process of collecting, sharing and processing information
- Use cases for data utilisation (including forecasts)

Measures

The following section sets out the recommended measures for the sustainable integration of PV into the electricity system, broken down by area of action. A summary of the measures for each area of action can be found at the end of the relevant section.

Measures in the «(System) operation» area of action

Maintaining system stability

It is Swissgrid's responsibility to ensure that system stability is guaranteed at all times within the Swiss electricity system and, in cooperation with European transmission system operators, within the European electricity system. This applies to both frequency and voltage, as well as to dynamic stability and short-circuit power. Even in an energy system with an increasingly decentralised generation mix, sufficient reliable operating facilities must be available to maintain these parameters. Some of the operating facilities for maintaining system stability can be provided by decentralised generation and storage. However, to ensure that these systems function in a way that supports the overall system, appropriate framework conditions – such as minimum requirements and default settings – must be established.

Swissgrid must continuously monitor and analyse dynamic stability and ensure that there is sufficient system inertia and short-circuit power – both during the planning phase of system operation and during real-time operation.

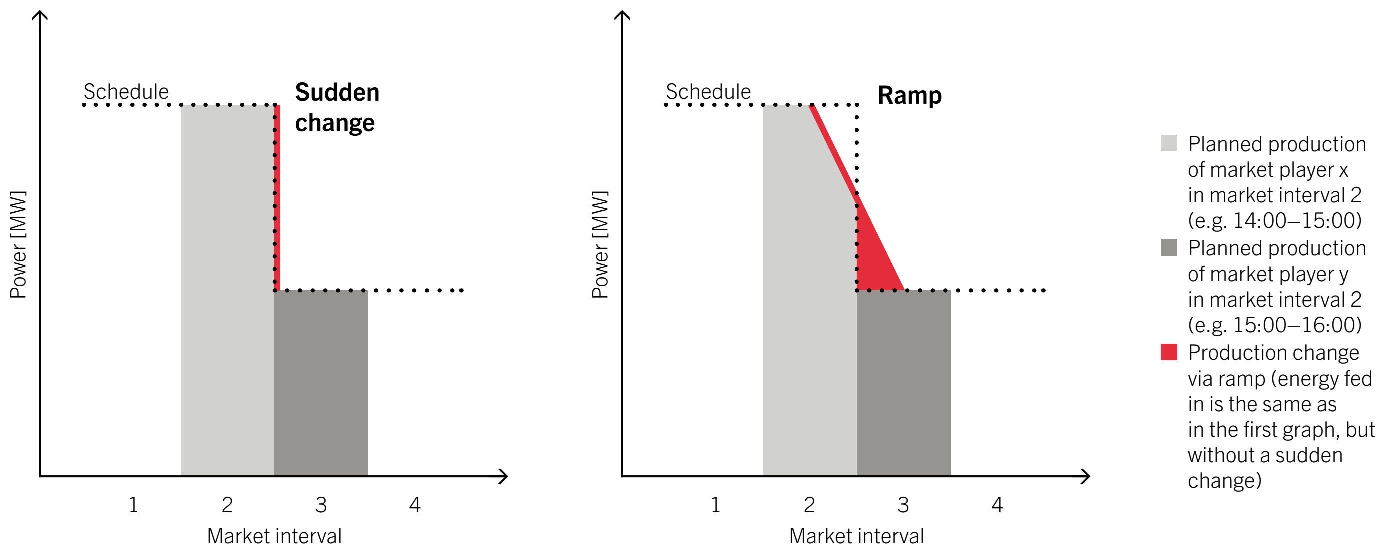
The decommissioning of large power plants in Europe (particularly thermal and nuclear power plants) means that the electricity system is losing what is known as «rotating mass» or «inertia». This positive, system-stabilising effect was provided free of charge as a «by-product» by the large generators at power plants. The loss of this inertia must be compensated for by other systems. This could be achieved, at least in part, by systems equipped with inverters, such as photovoltaic plants or batteries. The provision of inertia could be defined as a connection condition[12] or procured as a remunerated service by Swissgrid. For this to happen, the need for technical specifications and for an expansion of the current AS market to include a dedicated (market) product for inertia should be examined.

[12] Systems could be designed in such a way that their behaviour automatically supports the system under normal conditions («Stability by Design»).

Introduction of ramps for PV with controlled feed-in

The shift in the remuneration for PV feed-in from fixed feed-in tariffs to market-based prices is leading to planned adjustments in PV generation between individual market intervals, for example from one hour or one quarter of an hour to the next. If a large number of photovoltaic plants suddenly adjust their feed-in levels in response to changes in market prices, this leads to frequency problems at the start of each hour or quarter-hour. This phenomenon is known as «deterministic frequency deviations». To avoid this, balance groups responsible for power plant feed-in have to operate their schedules (or transitions from one market time unit to the next) with a ramp, even today. In other words, the change must not be sudden, but must take place gradually. The same rules must also apply to photovoltaic plants, as otherwise there is a significant risk that balance groups will be unable to meet their obligation to reproduce ramps. For this reason, the relevant control units in the photovoltaic plants must be configured in such a way that the feed-in also follows ramps in the event of a deliberate or controlled change – for example, in response to market prices.

Ramps in response to schedule changes



Checking and reading the operational settings of photovoltaic plants

When a new photovoltaic plant is installed, current regulations require an independent inspection body to verify that all the electrical engineering specifications have been met. The resulting security report must be made available to the relevant grid operator.

It is recommended that when drawing up the security report, the operational settings at the grid connection point (either on the inverter or in the EMS, depending on the technical situation) should also be checked and confirmed by the inspection body in the future. This is not yet the case, but it could prevent the system from malfunctioning due to inaccurate settings. Ensuring that plants have the correct settings will become more and more important as photovoltaic plants play an increasingly significant role in providing services for the overall system (see the «System stability» measure).

The settings of photovoltaic plants, particularly the protection settings, must be accessible for on-site reading using simple methods, even after the inverters have been commissioned – i.e. while the system is in operation.

It is important for the settings to be entered correctly even before checks are carried out for the security report. It is therefore necessary to provide appropriate training and raise awareness among the specialists responsible for installing and commissioning photovoltaic plants, with a view to ensuring the safe and effective operation of plants and their configuration. The introduction of a certification scheme for training in the commissioning of photovoltaic plants, with a focus on grid integration, should be envisaged.

Minimum requirements for cybersecurity
Digitalisation and decentralisation result in risks as well as opportunities. Whereas in the past, there were a manageable number of (large) production units, Switzerland's energy supply is now spread across hundreds of thousands of decentralised plants. A defined level of protection against potential cyberattacks is also required for decentralised plants and their control systems. This is because the greater the role played by PV in the electricity supply, the greater the vulnerability to potential attacks. Binding minimum requirements for photovoltaic plants are therefore also needed with regard to cybersecurity. What is more, these requirements must be effectively implemented and monitored (even for existing installations).

Behaviour of systems in the event of communication faults
Decentralised systems generally operate without a central control system. In the future, their importance to the electricity system will rise significantly, and they will increasingly provide active services such as flexibility or ancillary services. To make the behaviour of photovoltaic plants more predictable in the event of a (communication) fault, new systems should be designed to be «fail-safe». This means that they can be operated safely for a limited period (from a grid perspective) even without external control and/or functioning communication. Grid operators must therefore draw up guidelines stipulating that in the event of a communication fault, the installations must switch to a safe state specified in advance by the grid operator. This would ensure that even without active control or communication, photovoltaic plants would not actively disrupt the electricity grid through their behaviour, and their operational state would remain predictable.

Behaviour of systems during disruptions to grid operations
As well as establishing how to respond to communication faults, an operating mode for photovoltaic plants and prosumers should also be defined to specify how plants should behave in the event of a grid disconnection (supply disruption/ power system failure) before being reconnected. By defining the behaviour of plants directly within the system itself in such (exceptional) cases, a major source of uncertainty (i.e. the unknown behaviour of decentralised photovoltaic plants) would be reduced during the highly demanding and fragile phase of grid restoration.

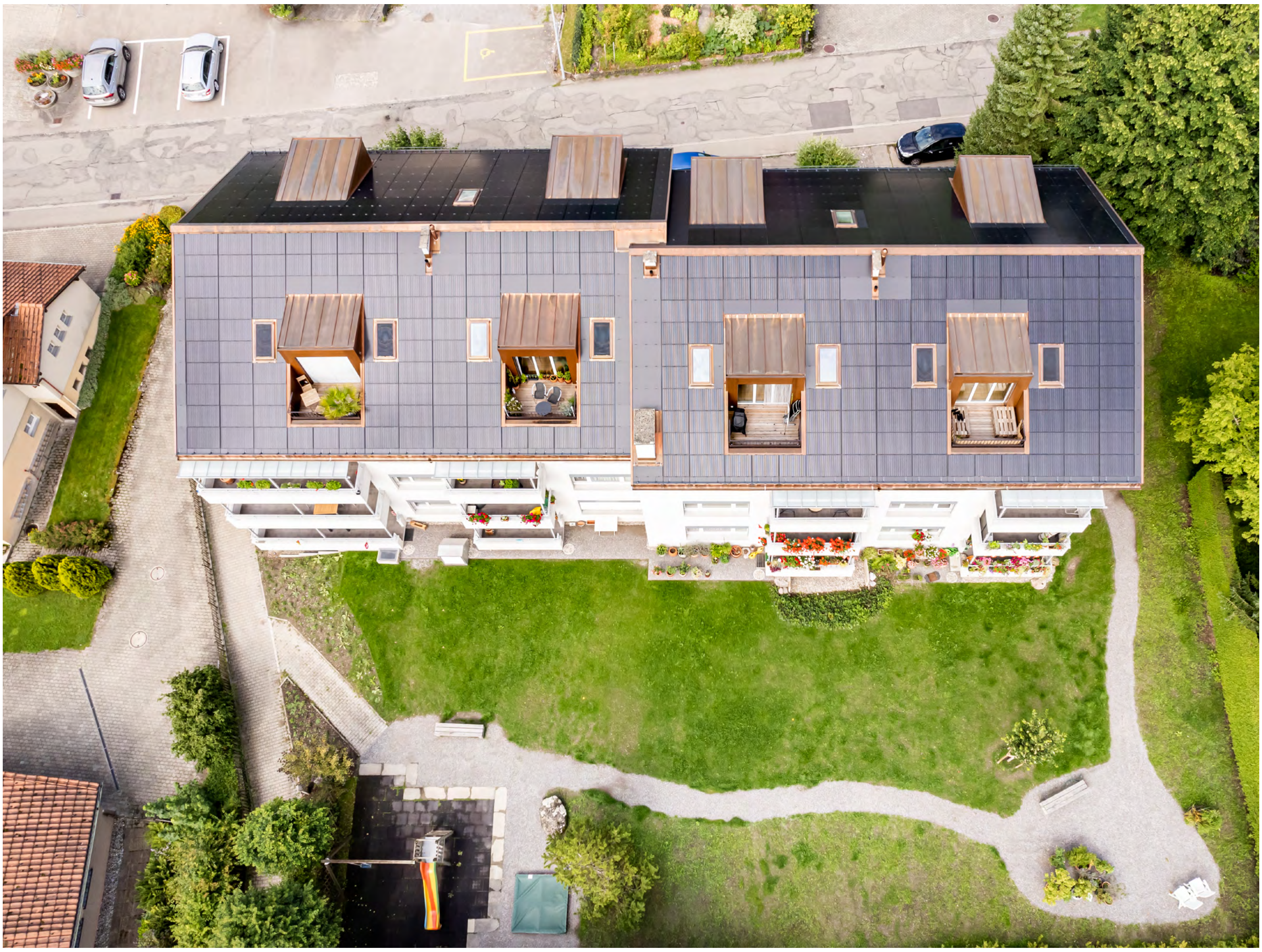
Summary of recommendations for the «(System) operation» area of action

@Swissgrid:
- Provision of sufficient operating facilities to ensure system stability
- Continuous monitoring of dynamic stability
- Procurement of inertia (connection specifications and/or market product)
- Introduction of schedule ramps for PV
- (Standardised) specifications for decentralised plants regarding their expected contribution to system stability

@Grid operators:
- Technical specifications for the ability to read the operational settings of photovoltaic plants
- Definition of the required behaviour of photovoltaic plants in the event of communication problems with the grid operator

@Legislator/ESTI:
- Checks of operational settings to be included in the security report
- Minimum specifications for cybersecurity (including effective implementation and monitoring)

@PV industry:
- Training and, where applicable, certification of specialist staff in the commissioning and configuration of photovoltaic plants (focussing on grid integration)



Source: BKW

Measures in the «Energy industry and market» area of action

Market-oriented PV feed-in and choice of trader

The decision on how and where to use or sell the electricity generated by photovoltaic plants should be market-driven, i.e. it should respond to supply and demand. If the market price is negative, there should be no financial incentive to feed electricity into the grid.

As not every photovoltaic plant has, or can have, direct access to the wholesale electricity market (power exchange), the PV feed-in to the grid should be purchased by an intermediary (trader) and sold on the market. Furthermore, pooling PV feed-in between one or more traders will ensure that the scale required to participate in the wholesale market is reached.

The most appropriate option for achieving this appears to be to replace the local supplier's current obligation to purchase PV feed-in with an obligation for the system operator to appoint a trader. This means that in the future, it will no longer be the local grid operator or supplier that is obliged to purchase and sell the electricity generated by PV; instead, the owner of the photovoltaic plant will have to select a trader. Choosing a trader must be simple and straightforward (with an obligation to accept customers, in the same way as for basic health insurance companies or Internet providers). The advantage is that specialist traders are better placed to sell PV electricity on the wholesale market than individual local suppliers, as is the case today. Competition between traders will give system owners a variety of options depending on their marketing preferences, such as price certainty versus maximisation of returns.

Marketing of flexibility

As well as marketing the PV electricity they generate, system owners or prosumers can also offer their flexibility on the market. Flexibility means adjusting the originally planned feed-in or feed-out. In other words, the prosumer reduces or increases the amount of electricity fed into or out of the grid as required (i.e. upon request by a third party). This is usually handled automatically by a power and energy management system – ideally in combination with a local battery storage system and/or controllable end devices (see the «Prosumers» area of action).

A distinction should be made between guaranteed flexibility that benefits the grid and flexibility offered on a voluntary basis. Under Art. 17c of the Electricity Supply Act, the distribution system operator is entitled to the guaranteed use of flexibility in a way that benefits the grid. No remuneration is paid for this. The grid operator may restrict no more than

3% of the energy generated annually at the connection point. In most cases, this is achieved by structurally reducing the grid connection capacity to 70% of the installed DC capacity in order to reduce the need for grid expansion driven by PV.

The system operator may choose to sell any additional flexibility for a charge. Depending on requirements, the customer may be a grid operator, Swissgrid or a market player. They make use of this flexibility as follows:

- In a way that benefits the grid, e.g. for local, national or international redispatch
- In a way that benefits the system, e.g. for frequency control or
- In a way that benefits the market, e.g. to optimise market prices or imbalance energy

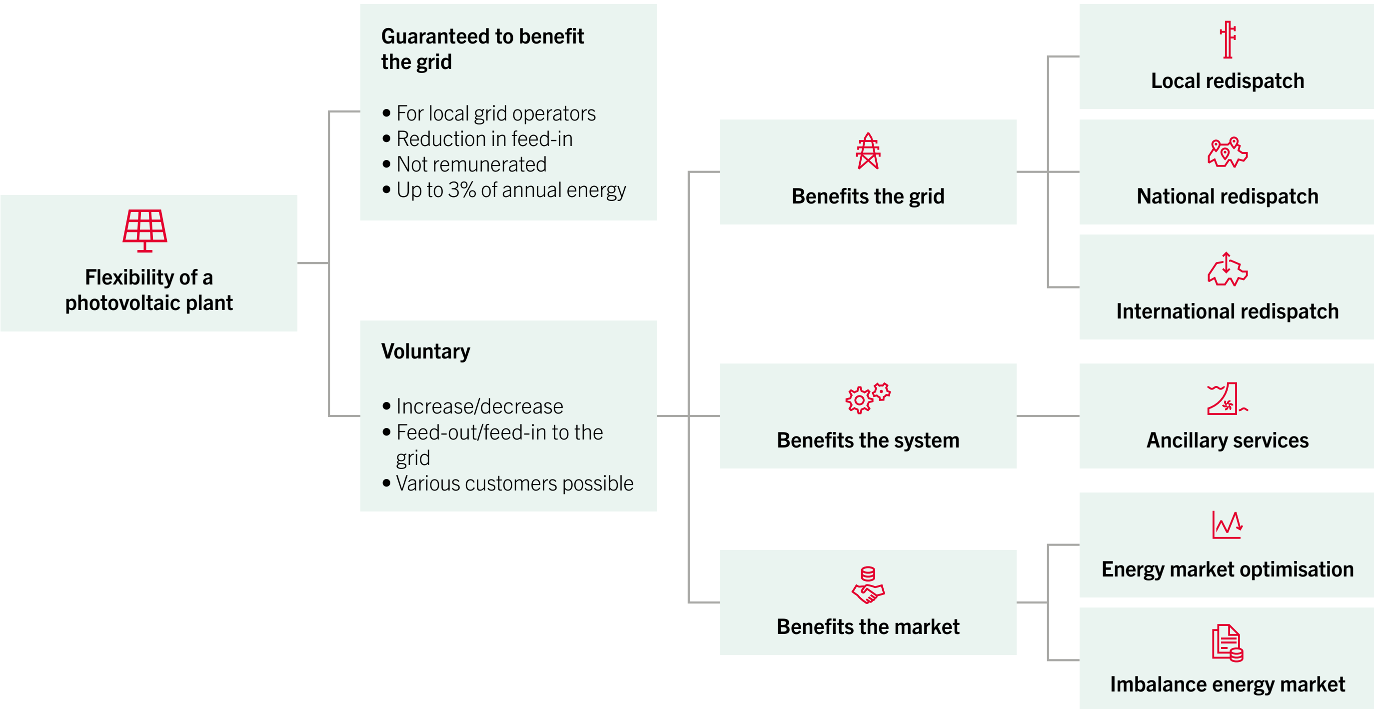
For practical reasons, marketing is usually carried out via an aggregator.

Given the fall in wholesale prices and feed-in tariffs for the electricity generated by PV, the sale of flexibility is set to become a significant source of revenue for photovoltaic plants/prosumers in the future (see the «Prosumers» area of action).

Coordination of decentralised flexibility

As there are different consumers and uses for decentralised flexibility, access needs to be coordinated. Otherwise, multiple or conflicting requests can be received from different players. Requests from third parties can also lead to local grid congestion. All the players involved and affected (flexibility customers, suppliers, the relevant balance group and grid operators) must therefore be provided with the necessary information and data in a timely manner, in a coordinated and calibrated form. Particularly when marketing is carried out by third parties, an information concept is required to protect all the players/third parties affected by flexibility requests (particularly suppliers and balance groups) from negative

Opportunities for marketing flexibility



financial consequences. Possible examples could include imbalances caused by flexibility requests, the foregone revenue issue or the catch-up effect. This coordination must include a mechanism for prioritisation and cascading. This ensures two things. Firstly, that priority is given to guaranteed flexibility requests in a way that benefits the grid. And secondly, that requests can be passed on to different players and grid levels. For this to happen, a standard for the exchange of information must be established for all players.

The technically permissible limits for the use of flexibility are set by the grid operator on the basis of local physical grid conditions. This means that the market-based marketing of flexibility takes place within the binding grid-related constraints set by the local grid operator.[13] The interaction between marketing and grid-side feed-in specifications can be managed via a flexibility platform or coordination platform (see the need for coordination mentioned above).

Summary of recommendations for the «Energy industry and market» area of action

@Legislator: • Enactment of an obligation to appoint a trader for PV production **@Market players:** • Transfer of price signals to PV producers • Creation of attractive purchase schemes (e.g. including the marketing of flexibility) for PV feed-in	**@Grid operators and market players:** • Establishment of a coordination process and standards for the exchange of information regarding flexibility requests, including prioritisation and cascading mechanisms • Specification of the permissible (physical) scope of action on the grid side*	**@System owners:** • Harnessing of opportunities for (voluntary) flexibility marketing as a source of revenue

* See the target scenario regarding «Dynamically optimised feed-in power» in the «Grid infrastructure» area of action

[13] See the target scenario regarding «Dynamically optimised feed-in power» in the «Grid infrastructure» area of action

Measures in the «Prosumers and system owners» area of action

Ways to generate revenue from a photovoltaic plant

Due to the increase in the amount of electricity being fed into the grid simultaneously by photovoltaic plants, the remuneration for electricity generated by PV is falling steadily, or even turning negative, particularly at times of high production (at midday during the summer months). For this reason, the optimisation of own consumption (primarily due to the associated avoidance of grid charges) and promotion of local consumption (LEC, ZEV, vZEV) will remain the main source of revenue for photovoltaic plants in the future. The second key source of revenue that is expected to make a greater contribution to the payback of investments in the future is the marketing of flexibility, as described in section «Energy industry and market». In terms of economic significance, the market-based feed-in of PV generation is of minor importance. This could be supplemented by potential subsidies for capacity expansion (particularly for plants without significant own consumption) and/or minimum returns and remuneration for reduced grid connection.[14]

Source: BKW

Potential sources of revenue for photovoltaic plants

Optimization of self-consumption	Commercialization of flexibility	Market-oriented feed-in	Subsidies / Minimum returns

As already mentioned several times, the feed-in of PV production into the grid must be based on demand, regardless of the size of the plant, and should be handled by traders acting as service providers. A remuneration scheme based on market prices is an important step towards ensuring that photovoltaic plants operate in a more system-friendly manner. Care must be taken to ensure that subsidies and levies do not weaken or counteract market signals.

To ensure the long-term economic viability of a photovoltaic plant, it must be able to respond flexibly to system, market and grid-related framework conditions, such as market prices or dynamic signals. Ideally, this can be achieved by combining it with a storage system and/or flexible behind-the-meter consumers (prosumers), including a power and energy management system. The flexibility of photovoltaic plants will therefore no longer be an option in the future, but a prerequisite for their cost-effectiveness.

Connectivity and interoperability requirements

In order for photovoltaic plants to optimise their feed-in in line with market conditions and to market their flexibility, they require a minimum level of connectivity. This means, for example, that they must at least be able to receive information on market prices and/or be directly controllable by the trader.

The interoperability of the photovoltaic plant must be ensured with both the controllable devices within the building (behind the meter) and the grid in a way that is as simple and standardised as possible. This can be achieved via an energy management system (EMS). In the future, the aim will be to optimise the prosumer's power as well as their energy. This will optimise not only the amount and timing of the energy fed into the grid, but also the power peaks associated with the feed-in or feed-out of energy, which are crucial for grid operations. Today's energy management systems should therefore be expanded to include power management. EMS will become power and energy management systems (PEMS). This

[14] In order to reduce the need for grid expansion driven by PV, photovoltaic plants should be given a (financial) incentive to apply for the lowest possible grid connection capacity per unit of installed DC capacity (see section 4.4).

involves establishing a standard that will considerably simplify the prosumer's experience, both during installation (by a solar installer) and during operation (e.g. SmartGridReady). Seamless interaction and coordination must be ensured between generation (photovoltaic plant), storage and consumption (heat pumping technology, electric cars, etc.), regardless of the manufacturer.

It is important for customers to be assisted by professional service providers. In the future, the installation and configuration of flexibility, storage and energy and power management must form part of a photovoltaic plant provider's extended core expertise.

Ensuring capacity expansion

Although sufficient electricity is already generated at certain times of the day (particularly in the summer), no structural surplus in production is foreseeable in Switzerland in the winter, even in the long term. However, if PV is to make a significant contribution to a secure supply of electricity in the winter as well, the installed PV capacity (kWp) must be increased even further – as envisaged in the Energy Strategy 2050. The fact that not every kilowatt-hour (kWh) of solar power generated is always needed must be taken into account. In other words, PV capacity should be geared towards winter demand, and summer surpluses accepted as a necessary evil. Incentives for expanding capacity should therefore be separated from operational incentives (i.e. when and how the plant is operated).[15]

It is the responsibility of policymakers to establish the necessary framework conditions for expanding domestic production capacity to meet the statutory expansion targets. The investment risk associated with sustainable photovoltaic plants that help meet statutory expansion targets must be manageable for small investors (e.g. by guaranteeing minimum returns over the lifetime of the system).

Summary of recommendations for the «Prosumers and system owners» area of action

@System owners:	@Legislator:	@PV industry:
• Construction of sustainable photovoltaic plants, ideally in combination with storage and/or flexible consumers (prosumers), including an energy and power management system • Guarantee of system connectivity and controllability	• Establishment of the framework conditions necessary to achieve the statutory expansion targets (a combination of specifications and financial incentives for capacity expansion) • Separation of incentives for the expansion of PV capacity from operational incentives	• Further development of EMS into power and energy management systems (PEMS) • Establishment of a communication standard to optimise all of the prosumer's systems • Installation and configuration of flexible systems as part of the core expertise of PV providers

[15] Specific solutions have already been developed at European level, such as «non-production-based contracts for difference». See the ENTSO-E position paper «Sustainable Contracts for Difference (CfDs) Design» (ENTSO-E, Feb. 2024)

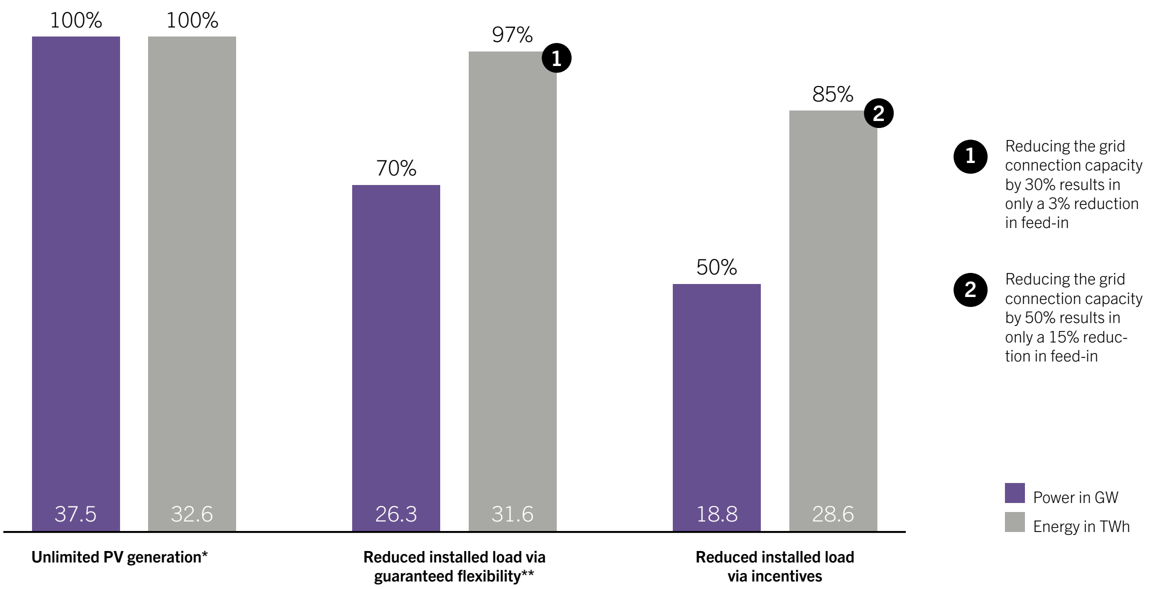
Measures in the «Grid infrastructure» area of action

(Remunerated) limitation of the installed load: «Power peaks don't belong in the grid»

Grid connection and grid expansion (where necessary) for 100% of the installed PV capacity make no sense, either technically or economically. The current legal requirement (a 3% restriction on annual energy at the connection point), in conjunction with the VSE electrical industry document, allows the grid connection capacity to be limited to 70% of the photovoltaic plant's installed DC capacity. This should be supplemented by an option for the grid operator to agree to a further long-term reduction in grid connection capacity in return for remuneration.[16] This will lead to better utilisation of the existing grid infrastructure and allow grid expansion to be avoided in the long term. If remunerating the grid connected party for reducing their installed load is more cost effective than making potential adjustments to the infrastructure (grid expansion), the grid operator should be able to oblige the grid connected party to implement such measures in the long term in return for remuneration. As this measure involves a limitation at the grid connection point, the system owner can either consume or store any energy that cannot be fed into the grid. Consequently, this measure will not mean that the energy is simply «wasted».

Taking local and regional grid topologies into account, the distribution grid will therefore be dimensioned to accommodate a much lower percentage of the installed PV capacity during the grid connection process. This will significantly reduce the need for distribution grid expansion driven by PV. This will also ensure that no peaks in PV generation are fed into the grid when there are no buyers in the power market due to the simultaneous nature of PV generation. This is particularly important given that the statutory expansion targets for PV (the planned energy targets correspond to approximately 40 GW of installed PV capacity) are much higher than Switzerland's peak demand (currently around 7–8 GW in the summer).

Ratio of grid connection capacity to potential feed-in



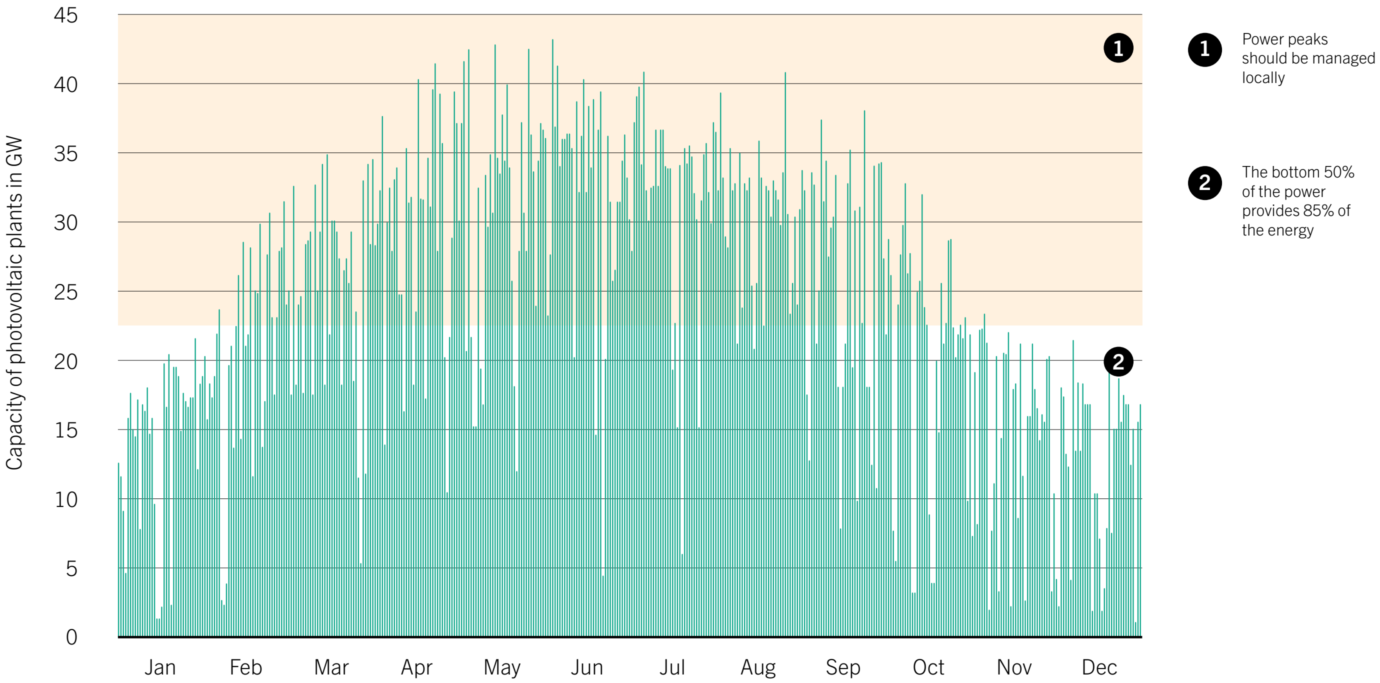
* Under Art. 5 para. 2 of the Electricity Supply Act (ESA), grid operators are currently obliged to connect all electricity producers; under Art. 15 para. 1 & 2 of the Energy Act (EnA), they are also obliged to purchase electricity from all (production) plants with a capacity of no more than 3 MW or 5,000 MWh

** Guaranteed use of flexibility in a way that benefits the grid in accordance with Art. 17c ESA and Art. 19c ESO

(all data according to Energy Perspectives 2050+, Zero Basis scenario; all figures are for Switzerland)

[16] Remuneration for reduced grid connection capacity should be regulated uniformly throughout Switzerland and be based on the lost revenue potential (marketing of PV production, including flexibility).

Local management of power peaks



Source: Christof Bucher, 2024 aeesuisse congress

Further development of emergency control to achieve dynamically optimised feed-in power

Where there is an immediate and significant threat to secure grid operation, the current legal provisions entitle the local grid operator to a guaranteed use of flexibility in a way that benefits the grid.[17] Today, the grid operator implements this (if they do so at all) using various established technologies that can be processed by all currently installed (photovoltaic) plants. Examples include relays on smart meters or the ripple control system.[18]

In the future, the grid operator must retain the ability to issue mandatory power system requirements regarding maximum feed-out or maximum feed-in, which would override all other flexibility signals in an emergency. Ideally, however, this should be achieved by dynamically defining the possible operating range. Firstly, this will enable the grid operator to reduce the feed-in power where necessary, in a similar way to the emergency control measures that are possible (but often not implemented) today. However, if permitted by the grid state (grid utilisation and local voltages at the connection point), the grid operator may also dynamically allow a higher feed-in power (i.e. higher than the contractually or legally agreed level).

Real-time monitoring of the distribution grid

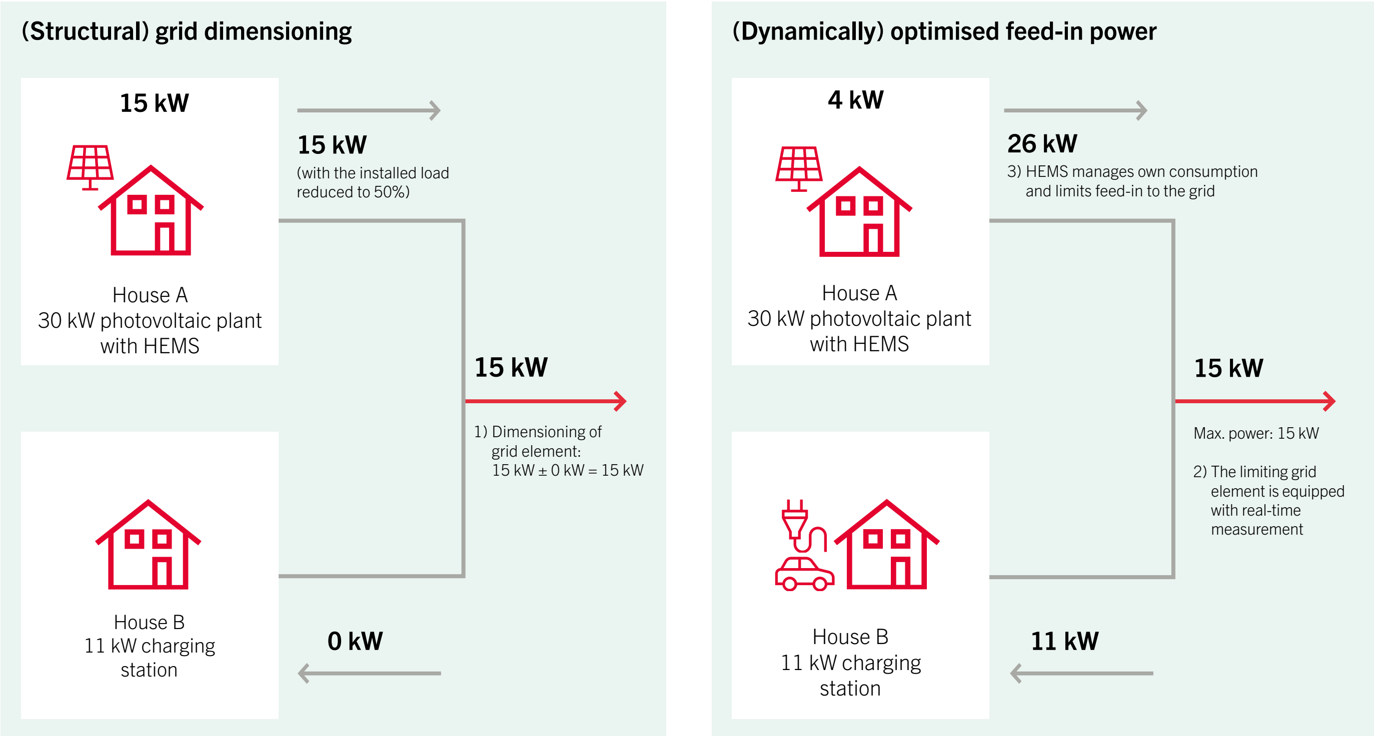
In order to calculate the permissible operating range, the distribution system operator must be able to monitor the local grid continuously (real-time monitoring) and communicate with the grid connected party (real-time sensors and actuators). The photovoltaic plant or the PEMS must be capable of continuously receiving and processing these parameters. The scope and implementation of this real-time system should be defined by the DSO. The interface between the DSO and the prosumer must be standardised throughout Switzerland (see also the information exchange standard mentioned in section Market and balance groups).

To avoid unnecessarily undermining the marketing potential of the system owner's flexibility, the grid operator's guaranteed access rights must be limited to what is technically essential.

[17] See Art. 17c para. 4 and 5 ESA

[18] Technically, it is the responsibility of the customer or their installer to ensure that all other flexibility signals are overridden in an emergency (as required by the Electricity Supply Act and the relevant technical connection conditions of the grid operators).

How dynamically optimised feed-in power works



HEMS: Home Energy Management System

Speeding up grid expansion

The measures suggested in this document are intended to reduce the need for grid expansion resulting from PV. Despite all the (optimisation) measures, grid expansion will still be needed in certain areas, depending on the grid topology (driven by generation or demand, according to the connection situation). This mainly concerns the distribution grid. The current obstacles to grid expansion must be removed in order to significantly accelerate grid expansion at all grid levels.

Summary of recommendations for the «Grid infrastructure» area of action

@Grid operators:	**@Legislator:**	**@System owners:**
• Development of regulations governing remunerated reductions in grid connection capacity to avoid the need for grid expansion • Further development of emergency control to achieve dynamically optimised feed-in power • Development of real-time monitoring and calculation systems for the distribution grid (sensors and actuators)	• Introduction of an option for grid operators to enter into binding agreements (including allowable remuneration) to reduce grid connection capacity • Acceleration of grid expansion at all grid levels	• Installation of a PEMS capable of receiving and processing signals relating to dynamic feed-in power

Measures in the «Controllability and incentives» area of action

Low-threshold marketing opportunities for decentralised flexibility

The (voluntary) marketing of flexibility from decentralised units should represent a key source of revenue for system owners and enable Swissgrid and grid operators to continue to ensure secure grid operation in the future, despite increased demand for flexibility. That is why it is essential for the participation of decentralised units (PV, BESS, charging stations, prosumers) in control energy markets to be made as accessible as possible to system owners. Access to the existing flexibility markets should be provided via an aggregator/pooler (see Flexibility marketing). The ongoing efforts to reduce barriers to entry into the balancing market should be pursued consistently. To do so, it is also necessary to adapt the current AS pooling concept to enable scaling to a large number of decentralised participants.

As well as exploring the further development of existing AS products, the extent to which these products can be supplemented by PV-specific products should also be examined (see Swissgrid's «PV for Balancing» pilot project). Products of this kind can take account of the specific characteristics of PV and may represent a cost-effective extension of traditional control reserve products.

Establishment of a flexibility platform and coordination mechanism

Given the increase in (voluntary) offers of decentralised flexibility (that benefits the system, the market and the grid on a voluntary basis), as well as additional demand for flexibility, the issue of how to prioritise and coordinate flexibility requirements must be resolved. The allocation of flexibility should be market-based: the customer who has the greatest need or benefit – and is therefore the most willing to pay – should be able to access this flexibility. The technical limitations of the grid must be taken into account to ensure that the activation of decentralised flexibility does not cause grid problems in the distribution grid concerned: the local grid operator specifies the technically (physically) permissible limits (see the target scenario regarding «Dynamically optimised feed-in power»). To achieve this, all the parties involved need to know the location of offers («nodal» information about where and in which grid the flexibility is located), and the photovoltaic plant must be able to receive and process at least two types of information: the technical limitations of the grid from the DSO and market-related signals/incentives from the trader.

Given the large number of players involved (system owners acting as flexibility owners, local grid operators, suppliers, flexibility traders, flexibility consumers and Swissgrid) and the geographical dispersion, a central flexibility platform with a coordination mechanism appears to be the most suitable option. The «TSO-DSO Coordination» pilot project is testing how local flexibility coordination of this kind could be put into practice.

Definition of end-to-end flexibility management

Even without a market-based flexibility platform, a uniformly defined end-to-end process for accessing flexibility is needed as a minimum requirement. This process must cover the following points:

- Prioritising different types of flexibility and ensuring that guaranteed flexibility usage takes precedence over other users. This means introducing rules governing how competing signals from different users are handled.
- Cascading flexibility requests among the various players / across property borders (e.g. passing on a control signal across different grid levels)
- Defining a control interface for the system owner's flexibility (transfer of flexibility requests «into the building»)

Summary of recommendations for the «Controllability and incentives» area of action

@Swissgrid:	@Grid operators (including Swissgrid) and players in the energy market:	@PV industry:
• Removal of barriers to entry into the balancing market for decentralised flexibility • Further development of the AS pooling concept • Assessment of the expansion of the AS market to include PV-specific products	• Establishment of a coordination platform for flexibility requests • Definition of a standardised end-to-end process (including information and communication standards) for accessing flexibility	• Development of a standard for flexibility management of prosumer systems

Measures in the «Data» area of action

Ensuring the quality and availability of master data

Master data refers to basic, generally constant information about photovoltaic plants, such as the installed capacity (DC and AC), the system's location, and its tilt and orientation. This data forms the basis for grid planning, system and grid operations, and feed-in forecasts. To ensure that this data is available to the required standard, there needs to be consistent collection and publication of master data on photovoltaic plants – in a timely and reliable manner. Grid operators, suppliers, aggregators and balance groups can only meet their respective responsibilities if they have access to high-quality master data. In addition to photovoltaic plants, this applies in principle to all relevant behind-the-meter prosumer systems, such as batteries, heat pumping technology and charging stations. Pronovo already maintains a list of photovoltaic plants – although its up-to-dateness and quality could be improved.

The allocation of individual photovoltaic plants to the balance groups is another important point. This information is not currently available and is a significant source of forecasting errors. There are often gaps in the flow of information regarding changes in the balance group allocation of photovoltaic plants (registration, changes). However, this information must be made available to all the relevant players in a centralised and timely manner – particularly in the event of changes.

Publicly available production data for the calibration of PV models

Based on master data for photovoltaic plants (installed capacity, location, tilt and orientation), market players and suppliers produce forecasts of the expected production of photovoltaic plants. To ensure that these forecasts can be continuously improved and optimised, these forecasts must be compared with the actual production figures. For players that do not have a direct (contractual) relationship with individual photovoltaic plants (e.g. [sub-]balance groups, aggregators, Swissgrid), it is difficult, if not impossible, to obtain the actual production figures for photovoltaic plants. The suggestion is therefore to select a nationwide network of photovoltaic plants (with and without own consumption), and to make their (anonymised) actual production data publicly available.
The resulting calibration network of photovoltaic plants can be used by all interested players as a reference for improving their forecasts and, where appropriate, as a «baseline» for flexibility requests.

Use of existing (private) measurements

In the debate over the (non-)availability of measurement data, there is often a failure to distinguish between the level of data quality that is essential for each specific purpose. This applies in particular to the distinction between private measurement data and calibrated metering data. Although calibrated data is required by law for billing purposes (grid operators/suppliers), this is not necessary for other applications (e.g. the calibration of PV models). Clearly defining the requirements and making (private) measurement data available (e.g. from the system owner's EMS) should encourage the use of existing data as far as possible without the need to set up additional hardware infrastructure.

Establishment and expansion of a Data Hub

The establishment of a Data Hub, as required by law, aims to standardise and improve data interchange between the various players in the Swiss electricity industry. As the availability of data is of crucial importance, particularly when there are large numbers of decentralised (photovoltaic) plants, the use cases already planned for the Energy Data Hub should be implemented as promptly and comprehensively as possible and expanded to include information from the Pronovo data base (see the «Master data» measure).
In addition, the extent to which data interchange via the Data Hub can be expanded to include real-time data in the future should be examined. This would result in significant benefits, particularly for PV generation balancing – i.e. the allocation to balance groups and the real-time monitoring of their zero balance position. This could be implemented using an open and standardised interface.

Summary of recommendations for the «Data» area of action

@Grid operators:	**@SFOE/Pronovo:**
• Definition of the (minimum) requirements for (measurement) data per use case and, where possible, integration of private measurement datan	• Timely and high-quality publication of master data, including balance group allocation • Establishment of a nationwide network of photovoltaic plants in Switzerland, with their actual production made publicly available to improve forecasts • Investigation of the possibility of adding real-time data to the Data Hub in the future

Implementation and conclusion

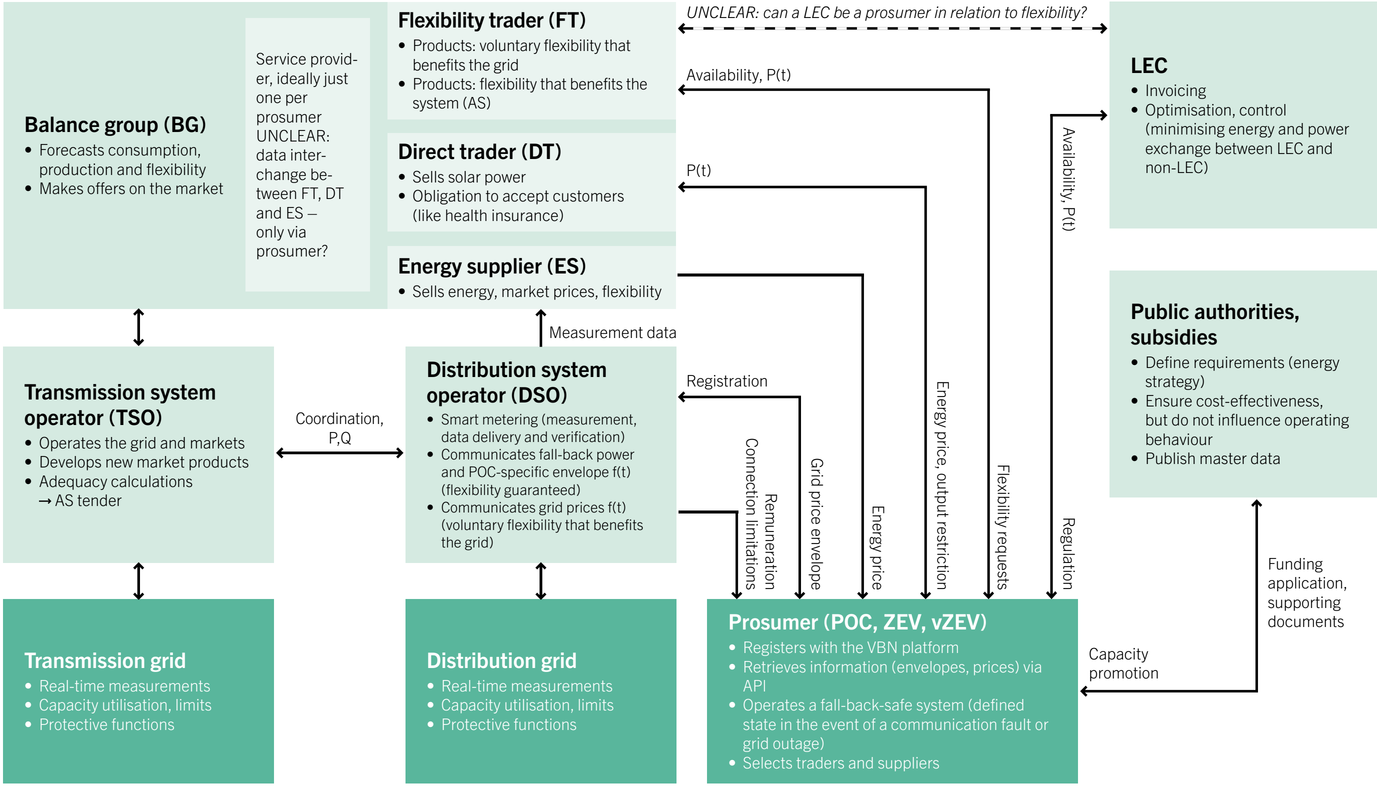
To guarantee the successful transformation of the energy system, and the integration of large amounts of installed PV capacity in particular, a coordinated, holistic approach must be taken by all the players involved. The challenges and areas of action arising from the increasing decentralisation and digitalisation of the electricity supply are complex and affect grid operators, suppliers, aggregators, system operators/prosumers, public authorities, technology providers and legislators in equal measure. No single measure can ensure the successful integration of PV into the overall system; only a comprehensive package of measures can do so – there is no one-size-fits-all solution.

As regards the timeframe for implementing the measures, some can be implemented immediately while others are intended for the very long term, and may also involve amending the legal framework conditions. It is important to give priority to those measures that will have long-term effects and would be difficult or costly to rectify. This applies in particular to the definition of standards and requirements for photovoltaic plants. Once a photovoltaic plant has been installed, any subsequent changes require costly modifications or retrofits – and would involve difficult discussions regarding who should bear the costs, transition periods etc. As the plants installed today will remain connected to the grid for twenty years or more, there is no time to waste in defining the necessary connection conditions and requirements.

The diagram below illustrates how the interaction between the players involved might work in accordance with the measures outlined in this document.

Source: Axpo

Suggested approach for system operation and system architecture: prosumers + distribution grid + transmission grid + market



Although this is a simplified overview, it is clear that promoting close cooperation between system owners, grid operators and market players is just as important as establishing legal and technical framework conditions that will allow innovation while ensuring security of supply. Looking at international developments can help us to adapt tried-and-tested approaches and guarantee the competitiveness of the Swiss energy sector.

In summary, it can be said that the successful implementation of the energy transition and the integration of PV require a wide range of measures and the active involvement of all the players concerned. Taking coordinated action throughout the entire process – by setting requirements for plants and introducing appropriate conditions for operation, marketing and data interchange – is the only way in which the PV capacity desired by policymakers can be successfully and securely integrated into the overall system.

List of abbreviations

AC	Alternating Current
BESS	Battery Energy Storage System
SFOE	Swiss Federal Office of Energy
BG	Balance Group
DC	Direct Current
DSO	Distribution System Operator
EMS	Energy Management System
ENTSO-E	European Network of Transmission System Operators for Electricity
ESTI	Swiss Federal Inspectorate for Heavy Current Installations
EU	European Union
GW	Gigawatt (equivalent to 1,000 MW)
GWh	Gigawatt-hour (equivalent to 1,000 MWh)
PV	Photovoltaics
kW	Kilowatt
kWh	Kilowatt-hour
kWp	Kilowatt-peak
LEC	Local Electricity Community
PEMS	Power and Energy Management System
MW	Megawatt (equivalent to 1,000 kW)
MWh	Megawatt-hour (equivalent to 1,000 kWh)
GCP	Grid Connection Point
AS	Ancillary Services
TSO	Transmission System Operator
TWh	Terawatt-hour (equivalent to 1,000 GWh)
VSE	Association of Swiss Electricity Companies
vZEV	Virtual pooling for own consumption
ZEV	Pooling for own consumption

Publication date: March 2026

Swissgrid AG, Bleichemattstrasse 31, 5001 Aarau, Switzerland
T +41 58 580 21 11, info@swissgrid.ch, www.swissgrid.ch